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THE FOYAITE-IJOLITE SERIES OF MAGNET COVE: A CHEMICAL STUDY IN DIFFERENTIATION. II.[1]

DISCUSSION.

In the table below are given the chief molecular ratios of those analyses of the Magnet Cove rocks which I am led to believe are the most reliable and representative. There are also

	I	II	III	IV	V	VI	VII	VIII
SiO_2	38.39	38.93	41.75	44.40	49.70	53.09	60.13	60.20
TiO_2	4.54	1.62	0.58	1.53	1.33	0.11	1.15	0.14
Al_2O_3	7.05	15.41	17.04	19.95	18.45	21.16	20.03	20.40
(FeO)	14.33	8.83	9.04	7.41	7.37	3.74	3.45	3.44
MgO	11.58	5.57	4.71	1.75	2.32	0.32	0.76	1.04
CaO	19.01	16.49	14.57	8.49	7.91	3.30	0.87	2.00
Na_2O	0.74	5.27	6.17	6.50	5.33	6.86	6.30	6.30
K_2O	0.75	1.78	3.98	8.14	4.95	8.42	5.97	6.07
MOLECULAR RATIO								
SiO_2	.640	.649	.696	.740	.828	.885	1.002	1.003
TiO_2	.055	.019	.007	.018	.015	.001	.014	.002
Al_2O_3	.069	.151	.167	.196	.181	.207	.196	.200
(FeO)	.199	.123	.127	.082	.102	.052	.048	.048
MgO	.290	.139	.118	.044	.058	.008	.019	.026
CaO	.339	.294	.260	.152	.141	.059	.015	.036
Na_2O	.012	.085	.098	.105	.086	.117	.100	.102
K_2O	.008	.019	.042	.087	.053	.090	.061	.065
$\frac{Na_2O}{K_2O}$	1.50	5.00	2.33	1.21	1.62	1.30	1.64	1.57
Specific Gravity	3.407	2.769	3.084	2.770		2.599	2.557	2.642

I. Jacupirangite.
II. Biotite Ijolite.
III. Ijolite.
VI. Arkite.
V. Covite.
VI. Foyaite, Diamond Jo.
VII. Pulaskite, Braddock's quarry.
VIII. Pulaskite, Type, Fourche Mt.

[1] Continued from p. 622.

inserted the figures for my two analyses of the Fourche Mountain rocks, which, although somewhat distant from Magnet Cove, undoubtedly belong to the same general regional magma. To render the diagrams less complicated the iron oxides are calculated together as (FeO).

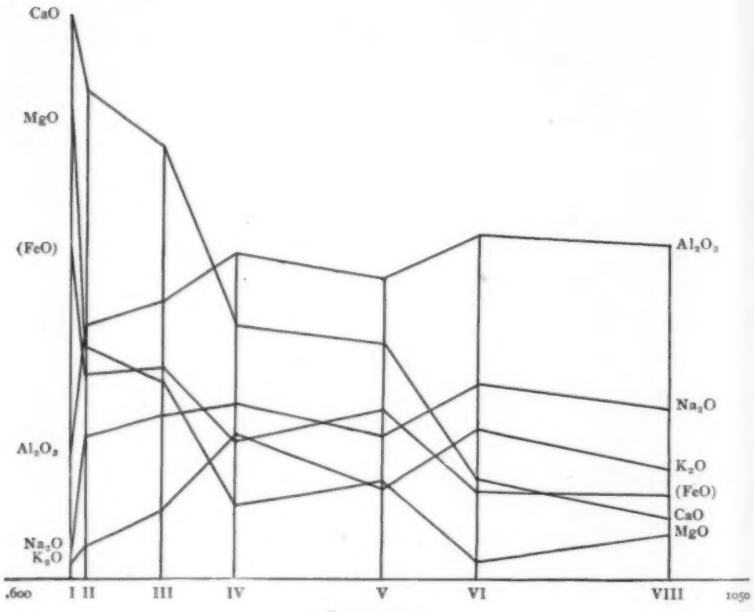

DIAGRAM 1.

It has already been explained that at Magnet Cove the arrangement of rocks from center to periphery is regularly serial, from basic to intermediate, *i. e.*, from II to VI. If, therefore, the analyses are plotted according to Iddings's method, using the silica values for the abscissae, the diagram will represent in a general way the variation of this particular magma in space. This was done in my former paper[1] for the earlier analyses, and the results of the present investigation are shown in Diagram 1.

[1] H. S. WASHINGTON, *op. cit.*, p. 404.

Comparison of the two shows that the curves, or rather zigzags, are much alike even though the analyses of (and consequently the abscissal positions of the figures for) arkite are different in the two. At the same time the new diagram is markedly more broken, and varies less regularly and continuously than the former. The regularly serial character of the first is thus apparently diminished, and what it was thought would be an excellent example of regular differentiation seems to turn out rather the contrary.

But, as Pirsson justly remarks, the use of SiO_2 for the abscissae is arbitrary, and, since this is one of the most important rock ingredients, its variation should also be shown in a manner directly comparable with those of the other oxides.

It would seem to be undeniable that this is a legitimate, indeed a most logical, method if the differentiated mass has not suffered disturbance and if circumstances permit the determination of the correct distances of the various differentiates from the center, since the diagram then represents, not only the compositions of the various phases, but their actual relations in space, both as to direction and as to relative position.

It often happens, as apparently at Magnet Cove, that the successive differentiation products are sharply separated from each other, transition forms being either lacking or very small in amount as compared with the main types. To correspond then with the actual state of affairs, the diagram should consist of steps, *i. e.*, horizontal lines of a length equal to the breadth of each zone, at the respective ordinal positions for each oxide.

Since, however, the analyses may be assumed to represent the average composition of each differentiation product, and we desire to study the course and the laws of differentiation, it is legitimate to represent the position of each constituent by a point, and the lines connecting these will therefore express the course of the differentiation of the mass of magma, even though, as an actual matter of fact, all the possible gradations represented by the curves may not be present. Such a procedure is quite in accordance with the general practice in chemical and

physical research, and this point is mentioned only because such methods have, as yet, found little application in petrography.

In order to construct the curves two important field data are required; the position of the center of the mass or area, and the relative distances from this of the various types analyzed.

By center is meant that of the innermost petrographic zone or core, not necessarily the geometrical center of the mass, as this petrographic center may be conceivably geometrically eccentric. Since, in many cases, as here, we have only one section, a horizontal one, this point is not necessarily the center of the mass, but rather its epicenter, to use the seismological term.

Since the area of Magnet Cove forms a fairly regular ellipse with axes of about 5 and 3 kilometers, the center of the igneous area is easily determined. Its position is marked approximately by the Baptist church,[1] which lies in the small central exposure of biotite-ijolite. Inasmuch as we do not know whether the plane of the present exposed area cuts the mass centrally or above the center, we cannot tell whether the central point of this is the true center of differentiation or not. It is probably not so. But as far as the types exposed are concerned this is of little moment, as their mutual relations would remain the same, or approximately so, in any case.

Having determined the center the next point is to determine the distances of the various types from this. It is obvious that for the proper plotting of the curves, and hence the study of the course of differentiation, this is of great importance, since the points which determine the various curves will be shifted in one direction or another according to the distances selected. This would alter very materially the slope of the curves, and even their character or shape, as by the shifting of the abscissal positions a straight line will become a curve, or a simple curve of the second degree may assume the form of an inflexed one of the third.

At Magnet Cove we cannot determine the abscissal positions by simply measuring the distances from the center to the particular spots where the analyzed specimens were collected,

[1] *Cf.* the maps in papers already cited.

because, owing to the elliptical shape of the area, a specimen (*e. g.*, covite) from near the end of the major axis may be at an actually greater distance from the center than one (*e. g.*, foyaite) from the end of the minor axis, though genetically inside the latter.

It would, of course be best to have several analyses of each type from different parts of the zones, both radially and circularly, so as to get the mean composition of each. But as that involves the making of very many analyses, we must be content at present with selecting what seem to be representative specimens, and assume that their analyses correspond to the average composition of each type.

Assuming this, two courses are open to us. We can either measure the distances from the center along a radial line on which all occur, or average the distances of the various occurrences of each type. The latter has been the process adopted here, since it seemed more likely to eliminate errors due to local conditions.

For each type measurements were made on Williams's map in many directions from the Baptist church to the middle point of each zone exposed, and the mean of these taken in each case. On the diagrams the abscissal positions of III, IV, V and VI, from the origin at II represent these relatively, as it is not necessary that the diagrams be of the same scale as the map. The position of the foyaite (VI) is not fixed as accurately as those of the others, since, being at the periphery, it is in great part overlaid by the surrounding shales. Small outcrops outside the main area, however, allow a rough estimate of its average distance, though it undoubtedly extends farther away from the exposed area than the few outcrops indicate.

In my former paper I assumed that the petrographic center of the area was in the "magnetite bed," and that this was the result of the decomposition of underlying jacupirangite. As, however, this is quite uncertain, it seems best for the purpose in view to disregard this area. For the present then the analysis (and the diagram position) of the jacupirangite may be neg-

lected. The same is true of the pulaskite analyses, these rocks lying quite outside the Magnet Cove area. All these rocks will be discussed subsequently.

We thus obtain the result shown in Diagram 2, where the points are connected by straight lines. In this, and the following, the vertical scale for SiO_2 begins .400 lower than the others, so as to condense the diagram and at the same time preserve

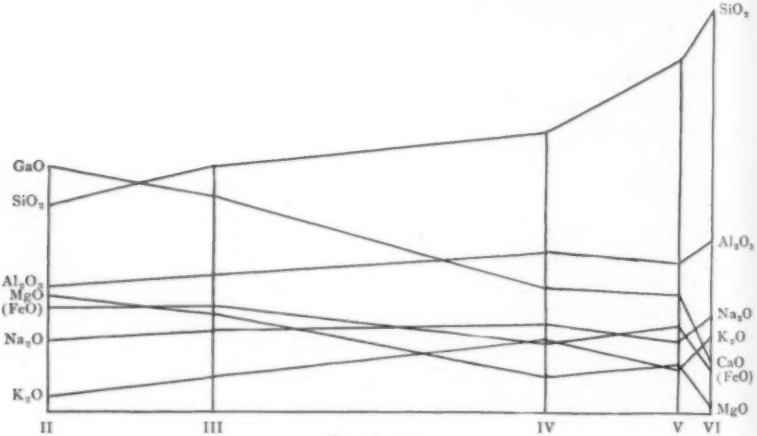

DIAGRAM 2.

the relative forms of all the curves (given later), and not flatten that of silica, as would be done if a smaller vertical scale were used for this than for the other constituents.

When Diagram 2 is examined it is clear that, with the exception of the values for covite (V), all the points of the respective oxides lie along very smooth curves. For convenience in further discussion the curves formed by the figures for II, III, IV and VI are plotted separately in Diagram 3. The values for V (covite) are entirely omitted from this, and the position and relationships of this rock will be discussed later on. The curves marked *F* and *M* will also be explained presently. All the curves, it may be mentioned, were drawn with a spline, so that the personal equation is eliminated as far as possible.

Within the limits from II to VI the curves are simple, that of SiO_2 alone showing inflexion about at the center of the diagram, rising sharply toward the right (acid end) and falling gently toward the left (basic end). Most of the curves are quite flat, especially those of Al_2O_3, Na_2O and K_2O, which approximate straight lines. At the same time they are all distinctly

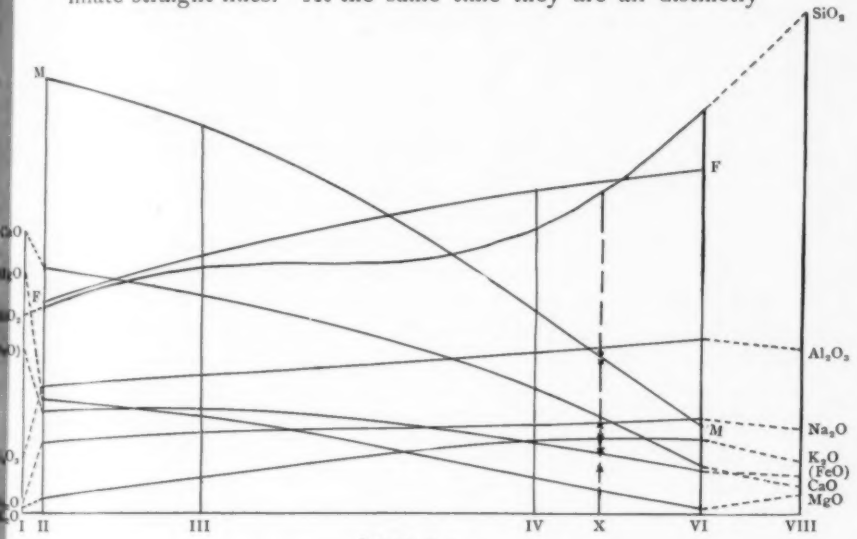

DIAGRAM 3.

curves and not strictly linear.[1] It will be remembered that Pirsson[2] says that all of the lines of his diagram should probably be drawn as very flat curves (much flatter than these), and these observations are in accordance with the conclusion of Harker,[3] that strictly linear series of rocks are of rare occurrence.

With the exception of SiO_2, which is inflexed and that of

[1] This is best seen in the large-scale drawing from which the diagram is reproduced.

[2] L. V. PIRSSON, *op. cit.*, p. 571.

[3] A. HARKER, JOUR. GEOL., Vol. VIII, p. 392, 1900.

Al_2O_3, which is almost a straight line but slightly convex,[2] all the curves are concave[1] (toward the bottom).

The curves divide themselves naturally into two groups, according to general direction. Those of SiO_2, Al_2O_3, Na_2O and K_2O ascend toward the right (the periphery), the three last almost arithmetically. It will be noticed that the K_2O curve ascends more rapidly than that of Na_2O to a point a little to the right of IV, when it drops a trifle more rapidly. This is expressed in the series of the ratios of these two oxides, already given in Table I. The second group is that of (FeO), MgO and CaO, which descend toward the right, and at a greater rate than those of the other group rise, SiO_2 excepted.

It may be noted, by the way, that if TiO_2 be plotted with SiO_2, the curve of the sums of the two becomes rather more flat (especially about IV), and the inflexion at the left is almost overcome. For facilitating this observation I have put the molecular ratios of TiO_2 next to those of SiO_2 in the table, though it would complicate the diagram unnecessarily to put in this joint curve. This seems to confirm the general belief that TiO_2 plays the part of an acid radical, like SiO_2, in rock magmas.

The general results can be concisely shown by plotting the sums respectively of the "ascending" and the "descending" oxides, except silica. We then get the two curves *F* (that of Al_2O_3, Na_2O, K_2O) and *M* (FeO, MgO, CaO), on the line of which all the determining points fall very exactly. They are both decidedly concave, *F* ascending and *M* descending, and their smoothness and regularity are very striking.

These results are in strong harmony with those of Pirsson, and the general characters of the curves in each diagram are very similar, though there are some differences in detail. Thus all his curves are much flatter, the SiO_2 does not show signs of inflexion, and the Al_2O_3 is concave and K_2O convex, while in mine these two are reversed. But these are small matters, possibly due to the abscissal distances at Yogo Peak not being as

[1] The terms convex and concave will be understood as referring always to the *X* axis, the bottom of the diagram.

easily ascertainable as at Magnet Cove. The general conformity of the two is very good evidence to show that, if plotted according to their spacial (*i. e.*, genetic) relations in the mass, the analysis of the components of an igneous complex will furnish regular curve. This fact is almost proof positive of the view that the variation of rocks is due to differentiation of some sort.

Whether this differentiation is always as is now believed, viz., that the oxides of Al, Na and K tend to segregate in one direction, while those of Fe, Mg and Ca segregate in another, as well as the process by which these changes are brought about, are separate questions, which further investigation must settle. It may be that the general course indicated by the diagrams of Pirsson and myself are typical of all rock differentiation, or it may be that with magmas of different character the course of differentiation may be radically different, and that the same oxides do not always tend to go together.

At any rate, it may be confidently expected that where a mass of magma has been differentiated *in situ* and is of approximately regular shape, has not been subjected to secondary disturbing conditions, and the exposures sufficient, we can express the relations of the differentiation products and the course of differentiation mathematically, as has been done in these two instances. Of course, for this purpose, it is absolutely essential that the analyzed specimens be representative, and that the analyses be complete and accurate. Otherwise the curves will be misleading or else uneven zig-zags, only rough approximations to the truth, and possibly not even that. There must also be present at least three differentiates, as otherwise only straight lines connecting the two can be drawn.

The fact that the SiO_2 curve is the only one which is inflexed, and that it runs very sharply up toward the acid end, leads to some interesting conclusions. Since, toward the acid end, the curves of (FeO), MgO and CaO drop much more rapidly than those of Al_2O_3, Na_2O and K_2O, it is evident that at a short distance to the right (in other words with a slight increase in

silica), they will practically disappear if the differentiation continues as indicated by the body of the diagram. Further differentiation in this direction then would lead to the production of a purely feldspathic or feldspathoidal rock. If continued still further quartz (free silica) would appear and the rock become aplitic in character. Finally, since the silica is increasing at a rapid geometrical rate, while the other constituents are dropping, the extreme result of differentiation in this direction would be pure quartz.

This inference is obviously in line with the experiments of Barus and Iddings[1] which indicated that in igneous magmas SiO_2 plays the rôle of electrolytic solvent, analogous to that of H_2O in aqueous solutions. This result is also in harmony with the experiments and conclusions of Lagorio[2] and Morozewicz,[3] who come to the conclusion that the predominant magmatic solvent is composed of silica and alkalis, and that it has the power of dissolving large amounts of alumina. The results obtained above would indicate that alumina itself is an essential constituent of the solvent, and it would also seem that there need be no stoichiometrical ratio between the four constituents. As has been indicated above, however, it will not do to push conclusions too far from such meager data, and it is by no means necessary to infer that a rock solvent of this character is the only possible one. But it will be as well to defer all discussion of these topics until more complete data are available.

The comparative rarity of occurrences of purely or very highly siliceous igneous rocks may presumably be ascribed to the fact that long before this phase of differentiation has been reached, the mass will, in most cases, have become solid (owing to the high melting point and great viscosity of such mixtures), and hence incapable of further change in this way.

It is of interest to note in this connection that a specimen of "aplite" has been collected by Dr. Weed, and is now in the

[1] BARUS and IDDINGS, *Am. Jour. Sci.*, Vol. XLIV, p. 248, 1892.

[2] LAGORIO, *Min. Pet. Mitth.*, Vol. VIII, p. 508, 1887.

[3] MOROZEWICZ, *Min. Pet. Mitth.*, Vol. XVIII, p. 235, 1899.

United States Geological Survey Reference Collection (No. 813). It is of a small dike, about one and a quarter inches wide, cutting the shale near Neusch's gulley, which it has metamorphosed. I am indebted to Dr. Ransome for the examination and description of this specimen which he sent at my request. "Under the microscope, the dikelet is seen to consist almost wholly of cloudy alkali-feldspar, with no quartz or nephelite, and a little biotite. With high power, the feldspar (between crossed nicols) all shows the fine shadowy striping indicative of a soda-bearing feldspar." Two garnets also occur at the borders of the dike. The occurrence of this aplite dike is clearly corroborative of the view of the course of differentiation which has been just expressed, and it is probable that further search would reveal others which have heretofore escaped notice.

Turning to the other end of the diagram, there is good ground for the belief that there must be inflexion upwards of one or more of the curves beyond II to the left. If the curves are extrapolated to the left, at a distance, let us say, equal to that between II and III, the sum of the constituents reduced to precentages amounts to only 55.6.

It is obvious therefore, either that some other component of the magma than any of those plotted is greatly concentrated at the basic end, or else that the curves of one or more of the plotted constituents must run very sharply upward, thus causing inflexion.

In the former case a probable additional constituent would be P_2O_5, which would yield, with high CaO, MgO and (FeO), an apatite-rich pyroxenite like that of Ahvenvaara in Finland,[1] or with disappearance of SiO_2, an apatite-magnetite rock like that of Alnö.[2] If TiO_2 should be the constituent to assume extraordinary proportions toward the basic end, we would expect, with disappearance of SiO_2, titaniferous magnetites, or such rocks as the magnetite-perofskite rock of Brazil, described by Derby.[3]

[1] V. HACKMAN, *Bull. Com. Géol. Finl.*, No. XI, p. 36, 1900.

[2] *Cf.* ROSENBUSCH, *Elemente*, No. 3, p. 133, 1898.

[3] O. A. DERBY, *Neues Jahrb.*, 1894, Vol. II, p. 297.

Such products are, however, very exceptional, and are only to be expected in cases of very complete differentiation. In general we would only look for sharp upward inflexions of the (FeO) and MgO curves, which would yield, with the slowly dropping silica and the high CaO, a pyroxenite rich in magnetite. This is just the character of the jacupirangite of Magnet Cove (I), and of those of Brazil and Alnö, and I have indicated its connection with the others accordingly by the dotted lines to the left.

Inasmuch as the specimens of this come from a small isolated mass outside the main area, its relations to the other types are uncertain, and its diagrammatic position has been given on the basis of its silica content. It seems to be probable that if, as is likely, such a rock is connected genetically with the others, its abscissal position should be considerably more to the left. As this rock is met with in the immediate vicinity of the main area, and is a theoretically possible differentiation product of the magma, it seems reasonable to assume that the section at Magnet Cove cuts the mass some distance above the center, and that below the biotite-ijolite is a core of jacupirangite, as previously supposed.

It is obvious from the theoretical discussion, as well as from observations here and at similar regions, that the relations toward the basic end are far more complex than at the acid end. This arises from the fact that the oxides involved here are capable of more numerous mineralogical combinations, and also because elements which are only present to a small extent in the body of the magma may here assume proportions of great importance. The fact that these extreme basic differentiation products are far more common than the purely siliceous ones may be ascribed to the greater fusibility of magmas of a basic character, and the consequent possibility of differentiation among them at temperatures when the more acid end of the series is solid.

In this connection attention may be called to the fact, analogous to the segregation of TiO_2 and P_2O_5 at Magnet Cove

and Brazil, that in large steel castings, such as those for modern artillery, etc., there is a very marked concentration of "impurities," as phosphorus and sulphur, toward the center of the mass.

As all the curves are so smooth and well defined, it seems highly probable that equations for them could be found and that their properties as such could be discussed. In this way we could get at an exact knowledge of the law of differentiation, in this particular case at least. It is a matter of regret that I am not mathematician enough to do this, but there are other applications of the data at hand which are capable of simple mathematical treatment.

Since the area of Magnet Cove is a fairly regular ellipse, and the zones of the various types are concentric about the center, by taking the average distance of each we practically reduce the ellipses to circles, the average distances being the radii.

Now, since II is at the center, if we suppose Diagram 3 to be revolved about the vertical line at II as an axis, it follows that the solids of revolution so generated by each of the curves (with the bounding lines at the sides and bottom), will represent the amount of each oxide in the original magma, and that their sum will represent the composition of the magma as a whole, before differentiation.

This is not strictly true, since we are ignorant of the exact shape and extent of the complex, but as a first approximation and an illustration of the method, it will be of interest to calculate the results which are obtained on this basis. As a matter of fact, the recent description of the Shonkin Sag laccolith by Weed and Pirsson[1] renders it extremely probable that the foyaite is present in far greater relative amount than the surface exposures indicate. This would necessitate a very considerable correction, but, as we have no means at present of estimating this, it will be as well to give the figures based solely on the field observations, leaving possible corrections for the future.

The process of calculating the various volumes is very simple in theory, but somewhat complicated and laborious in practice.

[1] WEED and PIRSSON, *Am. Jour. Sci.*, Vol. XII, p. 1, 1901.

As it is a somewhat new departure in petrography it may be of use to others to outline the method which I have employed. The curves shown in Diagram 3 were plotted on paper ruled in inches and tenths. The particular scale is simply a matter of convenience, and it is not necessary to reduce the percentages to 100, as we are dealing with relative amounts.

The formula employed is well known, being the second of Guldin's theorems, viz., the volume of the solid generated by the revolution of a closed curve or plane figure about an axis in its plane, but exterior to itself, is equal to the product of the area of the generating curve into the path described by the center of gravity of the revolving area.

$$V = 2\pi r A,$$

where V is the volume, r the distance from the axis to the center of gravity, and A the area of the plane figure.

The areas of the curve, *i. e.*, of the space embraced within the curve itself, and the limits of the diagram, are easily found, either by counting the squares, or by calculation of the area of the trapezoids formed by the respective chords and the limiting lines, and addition to these of the areas embraced between the chords and the curves.

The centers of gravity are found by dividing the trapezoids into two triangles, and finding their centers of gravity, when the center of gravity of the trapezoid will be at the intersection of the line connecting the centers of the two triangles and one connecting the middle points of the two parallel sides. In the case of the more curved lines a correction must be made for the area between the chord and the curve, but this will always be small. SiO_2 was regarded as composed of the large rectangle from .400 below the bottom of the diagram to .249, and the space between this upper boundary and the inflexed curve.

The resultant volumes, being based on the molecular ratios, have to be multiplied by the molecular weights of the respective oxides, in order to arrive at the percentage composition of the whole. In this way I obtained the following figures, which are given in full to illustrate the method.

	A	r	V	V × mol. wt.	Percentage	Mol. Ratio	
						Found.	Calc.
SiO_2	52.0	4.	1306.2	90576.0	47.24	.787	.787
	6.0	5.4	203.4				
Al_2O_3	14.0	4.25	375.7	38321.4	19.99	.196	.201
(FeO)	8.25	3.5	181.0	13032.0	6.80	.094	.074
MgO	5.9	2.9	107.4	4296.0	2.24	.056	.029
CaO	16.2	3.5	356.1	19941.6	10.40	.185	.117
Na_2O	8.1	4.1	208.6	12933.2	6.75	.109	.110
K_2O	8.8	4.75	134.2	12614.8	6.58	.070	.090
					100.00		

Of the Magnet Cove rocks this resembles most that of arkite (IV), especially as regards Al_2O_3, (FeO), MgO, and Na_2O, though it is distinctly higher in SiO_2 and CaO and lower in K_2O. Referring it to Diagram 3, its position established by means of SiO_2 is shown at *X*, and the points where this vertical is cut by the oxide curves are the "molecular ratios calc." of the table. The small crosses along the vertical indicate the positions of the various oxides as found. They can be identified by the values in the table.

It will be observed by reference to the diagram or to the last two columns of the table, that in the case of oxides whose curves are approximately straight lines, as Al_2O_3 and Na_2O, the found and calculated values coincide, while in the case of oxides yielding decided curves the value found is below that calculated.

This is in accordance with the demonstration of Harker[1] that if a series be linear the admixture of two or more members will produce a rock having the composition of a possible member of the series, while in a curvilinear series the mixture will not correspond to a possible member.

Another method for arriving at the composition of the magma as a whole would seem to be furnished by the determination of the mean point of each of the curves, thus giving the average composition. If the equations of the various curves were known, these could be calculated mathematically. But for practical purposes it can be done by determining, for each

[1] HARKER, JOUR. GEOL., Vol. VIII, p. 394, 1900.

oxide, the ordinal value for each successive tenth of an inch, and taking the mean. The result of this process is given in II below, that given by the previous process being given in I.

	I	II
SiO_2.....	47.24	45.44
Al_2O_3	19.99	19.06
(FeO).....	6.80	7.75
MgO.....	2.24	3.31
CaO.....	10.40	11.81
Na_2O.....	6.75	6.37
K_2O.....	6.58	6.26
	100.00	100.00

The two agree fairly well, and are of the same general character, though there are marked discrepancies, II being decidedly more basic in all respects than I. What may be the explanation of this, I am not mathematician enough to say. But the general agreement would indicate that one of the two, or their mean, cannot be far from the truth, *i. e.*, as near as the data at hand permit of approximation.

It is of interest to note that I have been unable to find the analysis of any rock which agrees at all closely with either of these two results. Those which are as high in alkalis being lower in bivalent oxides, while those which agree in this respect are lower in alkalis and alumina. Whether this indicates that there are serious sources of error in the method employed, or else that some undifferentiated magmas may possess chemical compositions not corresponding to those of rocks as yet known, is a question which cannot be decided here. It would seem as if there were nothing *a priori* contrary to the latter hypothesis.

In this connection Harker's[1] remark may be cited: "Given a series such that its diagram has markedly curved lines, the result of the admixture of two members may be something not only foreign to the series, but highly peculiar by comparison with igneous rocks in general." It is true that Harker was discussing the case of the mixture of two members of a series, but

[1] HARKER, *op. cit.*, p. 395.

differentiation and admixture (of two members of a series) may to a certain extent be regarded as inverse processes, so that the occurrence of a magma of this anomalous composition need not occasion surprise. Being rich in both of the generally antagonistic groups of oxides, it would be especially liable to differentiation. The general lability of the monzonitic magmas as regards the conditions controlling crystallization has been pointed out elsewhere.[1]

The general chemical composition can also be calculated by the relative volumes of the various phases, which has been the only method heretofore available. This would seem to be far more uncertain than the new method, which is based on the mathematical course of differentiation, since the ignorance of certain data may affect the result very seriously. Thus we cannot tell where the boundaries between two zones really fall, and (beneath the hornstone ridge especially) whether there may not be a zone of transitional material.

Assuming that the limits come half way between zones, and that they are of uniform thickness in all directions, we can easily

	Volumes	Weights
II	0.14	0.15
III	8.64	9.85
IV	38.27	39.15
VI	52.95	50.85
	100.00	100.00

SiO_2	50.02
Al_2O_3	20.89
(FeO)	5.87
MgO	1.36
CaO	6.89
Na_2O	6.86
K_2O	8.10
	100.00

[1] F. L. RANSOME, *Am. Jour. Sci.*, Vol. V, p. 370, 1898. H. S. WASHINGTON, JOUR. GEOL., Vol. V, p. 376, 1897.

calculate the volumes of the several spherical shells, which must also be assumed to represent the true ellipsoidal ones. The results are given below, including the relative volumes and weights (obtained by correction of the former for specific gravity), and the average composition deduced from this latter.

This result is notably less basic than the former calculated from the curves, and approaches somewhat closely to the compositions of the foyaite and the arkite, though in a general way intermediate between the two. This is so, since these two form (on this basis) 90 per cent. of the whole. It must be remembered, however, that this method is not based on curves, but on a succession of steps, and that the influence of the greater width of the more acid phases is intensified by their greater distance from the center. At the same time both methods indicate a magma rich in Al_2O_3, CaO and alkalis, low in SiO_2 and MgO, and with moderate iron.

Inasmuch as there must be a (probably rather large) correction made for the greater mass of foyaite, on the analogy of the Shonkin Sag laccolith, all these figures can, for the present, be regarded as only suggestive and illustrative of the method of investigation proposed, than representing exactly the actual state of affairs.

It is of course hazardous to theorize on such limited data as are yet available, but the methods indicated in Pirsson's paper and the present one would seem to be of not uncommon applicability, and well worth further trial in the investigation of other favorable localities. Indeed, as Pirsson has remarked,[1] "it would seem as if this should be the point of departure in the study of other series." The methods indicated certainly put the study of rock differentiation upon a purely mathematical basis, which in the hands of a competently mathematical petrographer, should surely lead to an exact quantitative knowledge of the laws which control this, and very probably, with the aid of physical chemistry, to a knowledge of the rationale of the process.

[1] PIRSSON, *op. cit.*, p. 576.

In my former paper I suggested as an explanation of the exceptional character of the Magnet Cove and Umptek laccoliths, in having the borders more acid than the centers, that the arrangement depended on the general chemical character of the undifferentiated magma. The process of differentiation was conceived to be, at least for such small bodies, in great part, a sort of fractional crystallization, the magma being regarded as a solution, so that, in accordance with the laws of cooling solutions, the solvent (*i. e.*, the portion present in excess) crystallizes out first around the borders on cooling of the mass.

From what has been learned of the composition of the magma, it is evident that, even though low in silica, it was originally of a decidedly leucocratic character. In other words, the potential feldspathic and feldspathoidal constituents predominated very largely over the calco-ferromagnesian. This is seen plainly from the relative weights of the spherical shells, but even the more basic composition derived from the curves shows the same thing. Thus the composition with 47.24 per cent. of SiO_2 may be obtained approximately by several different mixtures of all or some of the types analyzed, but in every case it necessitates taking from six-tenths to eight-tenths of foyaite, or foyaite and arkite. It seems scarcely necessary to give these calculations, which are purely empirical. The same composition may also be reduced to mineralogical composition in several ways, according to the assumptions made, but here, also, we get about two-thirds of leucocratic minerals.

The original body of magma, then, at Magnet Cove was, notwithstanding its low silica, decidedly leucocratic, as demanded by the theory, so that the alumina and alkalis, with the proper amount of silica for the formation of feldspar and feldspathoids, playing the rôle of solvent, would crystallize first, and hence form the outer portion of the mass.

The latest paper by Weed and Pirrson, already cited, is of great interest in this connection. Here it is shown conclusively that in the well-dissected Shonkin Sag laccolith the outer melanocratic shonkinite is present in enormously greater quantity

than the core of syenite, which, though basic, is distinctly leucocratic. The composition of the whole, then, would be melanocratic, as demanded by the theory, though with notable amounts of alkalis and alumina. The same general relations are assumed by analogy for the previously described Square Butte laccolith, whose magma thus possessed a similar strongly melanocratic character, *i. e.*, with a basic "solvent" portion, as was suggested.[1]

In this connection attention may be called to two other examples of differentiated masses in which the borders are more acid than the center. One is the igneous area at Alnö,[2] which is of special interest, since the rocks of this locality are very much like those of Magnet Cove. Another example is that of the Rieserferner massif in the Tyrol as described by Becke.[3] The central part of this is a typical tonalite, while the borders are composed of what is called "Randgranit." Although, unfortunately, no analyses are given, it is very evident from the descriptions and from the separations by heavy solutions that the border rock is decidedly higher in alkalis (especially potash) and silica than the main central mass.

Another region which offers close analogies in many ways with that under discussion is that of Ice River, in British Columbia, the rocks of which, collected by Dr. G. M. Dawson, have been briefly noticed by A. E. Barlow.[4] As the specimens were collected on a hasty trip, nothing is as yet known of their mutual relations in the area, but they form an unbroken series "from the most basic ijolite containing 36.988 per cent. of silica, to ordinary nepheline and sodalite syenites containing 53.638 per cent. of silica." Through the kindness of Dr. Barlow I have been able to examine sections of the ijolite, and it is interesting to note that, while closely analogous to the ijolites of

[1] H. S. WASHINGTON, *op. cit.*, p. 411.

[2] HÖGBOM, *Afh. Sver. Geol. Unders.*, No. 148, 1895. Map II. This is explained by Högbom as due to melting and absorption of the surrounding gneiss.

[3] F. BECKE, *Min. Pet. Mitth.*, Vol. XIII, p. 379, 1893.

[4] A. E. BARLOW, *Science*, N. S., Vol. XI, p. 1022, 1900.

Finland and Magnet Cove in most respects, yet that here hornblende replaces augite, thus differing from other known occurrences of this rock. It seems probable that these rocks are not as rich in lime as those of Magnet Cove, but higher in MgO and FeO.

In regard to the possible fourth type of laccolithic differentiation, which was mentioned in my previous paper, namely, that with a gabbroitic or peridotitic or pyroxenitic composition, the suggestion may be advanced here that representatives of this are to be found in the numerous sheets and dikes of diabase, which, as is well known, seldom show marked differentiation between the borders and the center. This is in accord with the view that in these masses the "basic" solvent is present to the almost total exclusion of the feldspathic portion.

As Pirsson has already pointed out,[1] the viscosity of the magma has an important bearing on the form assumed by an intruded mass. The highly viscous acid magmas will tend to arch up the overlying strata and form high laccoliths, while the more fluid, basic magmas do not possess sufficient viscosity to do this in general, and will hence form relatively thin intruded sheets. But, at the same time, many of these sheets are of thickness sufficient to allow of differentiation, if that had been possible through the composition of the magma.

Such sheets, then, may be regarded as the basic homologues of the acid, undifferentiated laccoliths of the Mt. Henry type, differing in form, but like them in that the solvent is largely in excess in the magma, and hence not susceptible to differentiation.

The abnormality of covite has been briefly noted, and a few words must be devoted to it before bringing this paper to a close. It will be observed on reference to Diagram 2 that for this rock the positions of SiO_2, Al_2O_3, Na_2O, and K_2O are below the corresponding abscissal points of the "normal" curves, while those of (FeO), MgO, and CaO are above. In other words, the positions of all the constituents of covite are consistently inversions of what may be called the normal (for Magnet

[1] L. V. Pirsson, *Eighteenth Ann. Rep. U. S. Geol. Surv.*, Pt. III, p. 586, 1898.

Cove); where the curve actually ascends, these would cause it to descend, and *vice versâ*.

Three explanations may be advanced for this. The first is, assuming that the covite is a primary differentiation product like II, III, IV, and VI, that the course of differentiation was not regular, but subject to comparatively large variations of an irregular character. This seems to be unreasonable *a priori*, and is also rendered untenable by the great regularity of the curves, if this type be left out of account, by the fact that the abnormalities are systematic in direction, and correspond inversely to the general characters of the respective "normal" curves, as well as by the field relations of this rock.

Another explanation is that the covite is a mixed rock, produced by the combination of either two differentiates of the magma, or one of its differentiates with foreign rock. That it cannot have been produced by mixture of arkite and foyaite is clear from the fact that many of its constituents are not intermediate between those of these two. It might have been produced by a mixture of foyaite and either ijolite or biotite-ijolite though its position in the complex militates strongly against this view. That it is not due to a mixture of the magma, or parts of it, with the country rock is evident from the composition of the latter, which is too low in MgO and CaO to form covite from foyaite, and too poor in alkalis to form it from the more basic members. Its position in the mass, between the foyaite and arkite, not on the extreme border, is also adverse.

The last, and most probable, hypothesis is that the covite is not the result of the primary differentiation which produced the other types, but of a secondary differentiation of one of the differentiaties of the primary process. In such a further differentiation we would expect the same oxides to differentiate in directions like those of the primary process, but in an intensified degree. This, in the case of the more basic of the two complementary secondary differentiates, would give rise to just the abnormalities noted in regard to covite.

Of just what particular phase of the primary differentiation

this secondary differentiate is a product it is a little difficult to say, but the evidence of Williams's descriptions, my own observations, and the mineralogical and chemical data, indicate that it was the foyaite sub-magna (VI) which has undergone this further change.

If this view be correct there must exist a complementary differentiate, a rock in which the positions of the various oxides are, as regards the "normal" curves, inverse to those of covite. That is, the loci of silica, alumina, and the alkalis would be above, and those of iron oxides, magnesia, and lime would be below, the "normal."

Whether we actually find this rock or not is more or less an accidental matter of erosion, etc. But a chemical analysis indicates that such exists in the case of the "foyaite" which occupies the small area in the northeastern part of the main mass, which was erroneously colored as ijolite on Williams's map.[1] This is a white, coarse-grained, holocrystalline rock,

	I	II	III	IV	Ia
SiO_2	53.54	53.09	49.70	53.11	.892
Al_2O_3	23.95	21.16	18.45	23.62	.234
Fe_2O_3	1.11	1.89	3.39	1.36	.007
FeO	1.24	2.04	4.32	1.47	.017
MgO	0.08	0.32	2.32	0.33	.002
CaO	0.71	3.30	7.91	1.51	.012
Na_2O	8.62	6.86	5.33	8.25	.139
K_2O	8.87	8.42	4.95	8.43	.094
H_2O (110°+)	1.09	1.13	1.09	....	....
H_2O (110°−)	0.14	0.24	0.25	....	....
CO_2	0.20	0.82	none	....	....
TiO_2	trace	0.11	1 33	....	....
P_2O_5	....	0.15	0.40	....	....
Other constituents	....	0.95	....	1.82	....
	99.55	100.48	99.44	100.00	

I. Foyaite, northeast part of area.
II. Foyaite, Diamond Jo quarry.
III. Covite, schoolhouse, western part of area.
IV. Mixture of eight parts of I, and one of III.
Ia. Molecular ratios of I.

[1] *Cf.* H. S. WASHINGTON, *op. cit.*, p. 394, note.

composed of alkali feldspar, with nephelite (partly altered to cancrinite), and rare grains of aegirine-augite. The position of this, outside the zone of arkite, is where we would look for such a differentiate of the foyaite magma.

The analysis, made by myself, of this rock is shown in I above, those of the primary foyaite and the covite in II and III, the molecular ratios of I being given in Ia, for comparison with those of the others on a preceding page. It will be seen that the values obtained for the main Diamond Jo foyaite, which is quite typical of this rock found around the border, are intermediate in every case between those for the other two rocks. Reference to Diagram 2 will also make evident the fact that the positions of the various oxides would be, as regards the normal curves, exactly the inverse of those of the covite. The figures for the new analysis fall above or below their respective curves, where those of covite are below or above. This is just what would be expected in the case of secondary differentiates, as has been explained above.

The results of a mixture of eight parts of I and one part of III are shown in IV. It approximates fairly well to the composition of the typical foyaite, especially in SiO_2, MgO, and K_2O, though Al_2O_3, and Na_2O are considerably higher, and iron oxides and CaO lower.

It may be of interest to give the calculated mineralogical composition of I, which works out as follows:

Orthoclase	52.3
Nephelite	36.9
Cancrinite	2.8
Aegirite	3.2
Diopside	3.7
Extra alumina	1.0
	99.9

The possibility of a secondary differentiation taking place in a primary differentiate is, it must be conceded, difficult to reconcile with the hypothesis already advanced, since according to this the differentiation takes place by a successive crystalliza-

tion, *i. e.*, solidification of the magma, and any such process is, of course, impossible in a solid mass of rock.

This difficulty, however, does not seem to be insuperable. The evolution of heat on the solidification of molten lava is a well-known phenomena, having been actually observed, and the same has been experimentally verified, and the amount of heat evolved on the solidification of diabase has been determined by Barus.[1] Therefore the crystallization of minerals from a molten magma is an exothermic change.

It is therefore conceivable that the solidification of a laccolithic mass may give rise to sufficient heat to remelt portions of it, which might easily remain liquid long enough for a secondary differentiation to take place. That this was actually the case at Magnet Cove cannot be definitely shown, but it is at least an explanation which has a certain degree of probability in its favor.

In regard to problems of interpolation and extrapolation, by which Pirsson obtained such close agreement between calculated and observed chemical composition, we are not in a favorable position, since the analyses which I have made exhaust the known main types of abyssal rocks at the locality. A comparison of the analyses of the dike rocks given by Williams with the curves in Diagram 3 confirms the supposition expressed in my former paper that the tinguaites and the nephelite-porphyry are aschistic, and that the fourchites and ouachitites like the covite, are diaschistic.

It was expected that the analyses of the Fourche Mountain pulaskites would fall in with the curves as laid down. But, determining the abscissal position by silica, it is found that Al_2O_3, Na_2O, and K_2O are below, and (FeO), MgO and CaO are above, what would be their "normal" positions, as will be seen on reference to the diagram.

Although these rocks are unquestionably derived from the same general magma, yet, as their distance from Magnet Cove is about forty miles, it is clear that we need not be surprised to

[1] C. BARUS, *Am. Jour. Sci.*, Vol. XLIII, p. 56, 1892.

find discrepancies, due to differences in the process of differentiation.

At Magnet Cove we have, without any doubt, the results of the differentiation in place of a small body of magma. This particular mass may have had originally the composition of the magma underlying the whole region, or it may have been itself a differentiate of this. Differentiation in such a large body of magma as that underlying the whole igneous region of Arkansas would naturally be likely to give rise to diverse products at different points, in which, however, could still be traced some of the original general characters of the whole. We are as yet scarcely in the position to deal with such intricate and obscure problems, but the results of Pirsson's investigations and of those embodied in the preceding pages seem to furnish a promising means of attack.

HENRY S. WASHINGTON.

PECULIAR EFFECTS DUE TO A LIGHTNING DISCHARGE ON LAKE CHAMPLAIN IN AUGUST 1900.

AFTER a period of long continued drought, when the ground was very dry, a thunder shower arose in the Adirondacks, which passed east, crossing Lake Champlain over Westport and along south of the crest of Split Rock Mountain. No rain fell north of the top of the mountain, but a very severe storm passed to the south. When the storm had nearly disappeared, a sudden discharge of lightning passed down from the clouds, striking about half way down the northern slope of the mountain, entirely outside of the rain area and into the dry trees and rocks. In about a half a minute a cloud of what appeared to be dust could be seen rising from among the pines and juniper bushes. This, however, in a couple of minutes proved to be smoke, and in less than five minutes a very well developed forest fire was under way. Fortunately, a number of persons saw the discharge and saw the fire start, and immediately hastening to the spot were able to extinguish the fire before it had burned over more than a small fraction of an acre.

The peculiarity of the discharge was immediately observed upon coming upon the locality. An old pine tree seemed to have received the most severe part of the discharge and was badly split in the familiar manner. In addition to this, however, a number of places were immediately noticed where the lightning had struck either into the rocks or into the dirt overlying the rock. In two cases the discharge into the rock was of such force as to split the rock, tearing up fragments weighing as much as fifty to one hundred pounds and scattering them about. In other places the discharge upon the rock was comparatively slight, producing simply small fractures in the rock, and in some cases the effect was so slight as to simply remove the dry moss, leaving a small white spot not as large as the finger-nail. These partial

discharges of such varying force were scattered over an area of perhaps thirty to forty feet square, the more violent ones being within twelve or fifteen feet of each other. Upon examining the point at which any one of these discharges struck, a white incrustation was apparent upon the rock, as if white paint had either been spattered about or had been spread over as a rough, branching, straggling line. These white incrustations, in some cases, could be traced for a foot or more down into the cracks between the rocks. In other cases, they were mere spots. These white streaks were, undoubtedly, the paths along which the electricity ran, and a superficial examination showed that the white was due to an incipient fusion of the surface of the rock. Unfortunately, it was not practicable to get satisfactory photographs of these markings or to bring in large specimens. Small specimens, however, were brought in, and have been subjected to investigation.

The probable explanation of the scattering discharge of this particular lightning is to be found in the extreme dryness of the ground. The cloud charged with electricity would, of course, induce the opposite kind in the trees and rocks immediately beneath it. Then, when the discharge came, it was necessary that each prominence should discharge to the cloud *individually*, because the ground connecting the different prominences was too poor a conductor to rapidly collect the quantities of electricity and discharge them through a single point, as is usually the case.

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A STUDY OF THE STRUCTURE OF FULGURITES.

SOME obscure problems in structures occurring within artificial and natural glasses (rhyolites, tachylites, etc.) receive light from the study of fulgurites, as representatives of instantaneous fusion, and frequently, as it will be shown, of equally rapid devitrification.

Hitherto, however, a constitution of homogeneous glass has been universally observed, under the microscope, in all sand-fulgurites, without the least trace of devitrification in the largest masses.[1] Occasional cloudy stains of brown iron-oxide and black manganese-oxide have been noted, and frequent enclosure of remnants of quartz-grains[2] and of bubbles, both more abundant near the outer walls of fulgurite.[3] In rock-fulgurites, a single instance of devitrification has been recorded. The results of examination of four fulgurites will now be described.

I. *Fulgurite* (lightning-tube) from sand, *Poland;* a small fragment, together with thin cross-sections, prepared by Mr. James Walker, of the New York Microscopical Society. This fulgurite is of small size, from 5 to 8 ^{mm} in diameter, with central aperture or lumen usually 2.5 to 4 ^{mm} in diameter, and glass wall varying mostly from 0.6 to 2.0 ^{mm} in thickness, roughened outwardly by adhering sand-grains in a continuous coating. The photomicrographs (Figs. 1 and 2) may serve to explain certain features as yet unrecognized in other fulgurites.

The wall presents, under low magnifying power, an apparently homogeneous glass, streaked by occasional cloudy wisps

[1] "A Perfect Glass," ARAGO (*Ann. d. Ch. et. d. Phys.*, Vol. XIX (1821), p. 290) and all later investigators.

[2] VON GÜMBEL, *Zeits. d. D. geol. Ges.*, Vol. XXXIV (1882), pp. 647–648.
J. S. DILLER, *Am. Jour. Sci.*, Vol. XXVIII (1884), pp. 252–258.
G. P. MERRILL, *Proc. U. S. Nat. Mus.* (1886), p. 84.

[3] Best shown in the longitudinal and cross-sections of a sand-fulgurite by A. WICHMANN (*Zeits. d. D. geol. Ges.*, Vol. XXXV (1883), Pl. XXVIII).

of brownish and reddish iron-stains, and besprinkled with swarms of bubbles of varying size.

The inner surface of the lumen is for the most part smooth and shining, with boundary sharply defined in cross-section

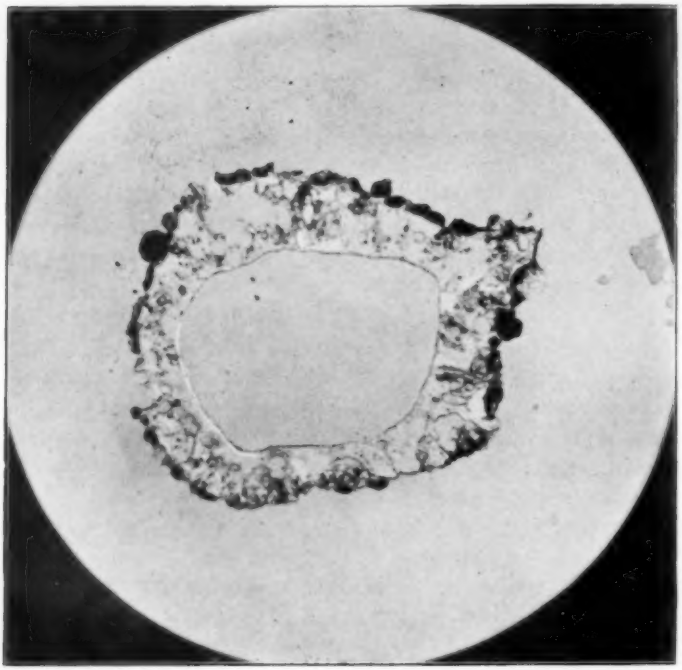

FIG. 1.—Sand-Fulgurite, Poland. × 10. Photomicrograph of cross-section.

(Fig. 1), as in other fulgurites; but, here and there, a few points, pustules and needles of glass are found to project, of a length up to 0.17^{mm}. For the origin of the central lumen an explanation long accepted has been that suggested by Watt for the hollows in a fulgurite-mass, "the expansion of moisture while the fusion existed.[1] In this cross-section the outline is

[1] *Phil. Trans. Roy. Soc. Lond.*, Vol. LXXX (1790), p. 302.

nearly circular, with maximum and minimum axes as 4 : 3 ; in another it is still more elliptical. This difference, common in sand-fulgurites, has been attributed to distortion of the tube by pressure of the surrounding sand upon the fulgurite while still plastic. In one cross-section, one side of the tube appears partly crushed together, with coalescence of opposite parts of the wall into a blebby mass of coarse bubbles and partial obliteration of the lumen. The characteristics of such a fulgurite seem therefore to be naturally divided into those developed during the sudden dilatation of the tube, and those which may have ensued during its quick compression and in places partial collapse.

In regard to the distribution of the bubbles or vesicles, three vaguely marked bands may be distinguished :[1] a marginal tract, next the lumen, comparatively free from vesicles and clear: a middle portion of the wall comprising most of the larger vesicles; and the gathering of dark swarms of the more minute vesicles toward the outer margin.

The last (partly shown in Fig. 2) vastly predominate in number over the larger vesicles, are almost universally spherical, vary greatly in diameter down to 1μ or less, and compose the dark clouds, seen under low magnifying power, on inner side of sand-grains adhering to outer side of the wall. Others are also dispersed more irregularly in lines and bands through patches of the glass (best shown under magnifying power of at least 300 times). A careful search was made among these dark bubbles, particularly the most minute, by means of a tenth-inch objective of good definition, for traces of enclosed water, but no liquid could be distinguished. From this I conclude that any watery vapor, derived from moisture present in the sand, has been mostly expelled in the explosions, and also that this has probably had far less to do, in expansion of the lumen and formation and compression of bubbles, than the elastic force evolved by sudden heating of the large volume of air occupying the interstices of the

[1] In a fulgurite from Milton, Florida, no definite order of arrangement occurred. (MERRILL, *loc. cit.*, p. 90).

sand-grains. The bubbles should therefore be more properly denominated air-vesicles (*luft-blasen*) than vapor- or steam-cavities (*dampf-poren.*)

The larger vesicles, which mostly occupy the middle part of the tube-wall, seem to have been produced by crowding together

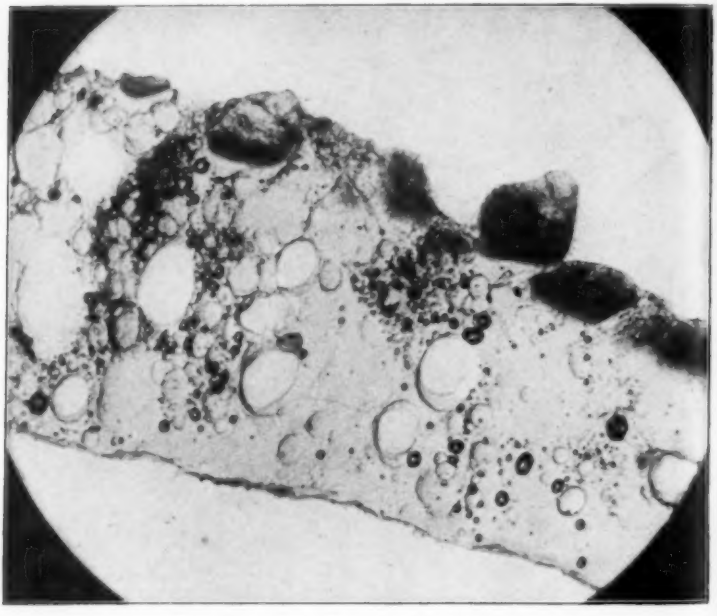

FIG. 2.— The same. × 50. Part of wall.

and coalescence of smaller ones. The largest, which have been perforated and emptied, in making the thin section, present light outlines, up to 0.2 to 0.3 ^{mm} in diameter, mostly elliptical, but also oval, pearshaped, lenticular, triangular, or squeezed together in groups, with contiguous walls flattened by pressure in direction tangential to the tube-wall. Even a particular vesicle may vary much in size and in form of cross-section at different depths, as if distorted after formation. The longer axes of the

elongated vesicles are in general disposed radially[1] toward the lumen of the tube, though occasionally one may lie obliquely or even at right angles to that direction, as if twisted around by a sudden thrust. All the facts seem to point to strong lateral or tangential compression of the vesicles within the surrounding glass wall, and to their consequent extension and distortion in the direction of relief.[2]

The sudden expansion of air and vapor by the electric discharge has thus effected the dilatation of the lumen, the generation of bubbles throughout the fused glass, and the coalescence of those first formed into the larger vesicles. The relief of this tension outwardly, toward the margin of the tube, first caused the radial elongation of the larger vesicles and extension of conical projections and wings from outer side of the plastic tube, aided, doubtless, by lateral offshoots of the electric current.[3] Then, in the moments succeeding the passage of the main current, the effects of sudden condensation, lateral contraction and recoil are shown in the instances of partial collapse of the tube, in the reverted distortion of vesicles, *i. e.*, inwardly toward the lumen, and in explosion of some bubbles nearest the lumen into pustules and points of glass over its surface. Where the glass retained its plasticity longer, the vesicles have recovered their normal spherical form; this condition seems to have been regained in nearly all fulgurites whose vesicles have been carefully examined by others. It is to be noted that elongated vesicles in radial position have been recorded in only two cases of rock-fulgurites, in both within partially devitrified glass, as found in one by Rutley and in the other by Wichmann; in the latter case (viz., fulgurite III, beyond) I have made the same

[1] A position already recognized in other fulgurites by Wichmann and Rutley.

[2] One writer considers "this radial arrangement . . . . possibly indicative of a rudimentary crystallization in the fulgurite glass" (RICHARDSON, *Min. Collector*, Vol. III (1896), p. 132).

[3] MERRILL, *loc. cit.*, 87. One consequence of these offshoots, and of the ozonized atmosphere thereby developed, is shown in the reddish stains, due to oxidation of iron, in the sand surrounding a fulgurite, to the distance of 3 or 4 inches; *e. g.*, in that found near Starczynow, Poland (ROEMER, *N. Jahrb. f. Min.*, 1876, pp. 33–40).

observation, in addition to fulgurites I, II, and IV. Their exclusive association, therefore, with devitrification may be a consequence of more sluggish movement and imperfect recovery from distortion within the more viscous crystallite-laden glass.

Another feature, quite distinct in the vesicles of larger size, is the separation of each from the surrounding glass by a limpid pellicle, never exceeding 0.2μ in thickness. This appears both in cross-section, with sharply differentiated outlines, and also in jagged remnants around the margin of an emptied vesicle, on surfaces of the thin section, like the edges of a broken eggshell. It may be considered a glass coating, suddenly chilled and condensed in contact with the bubble, at first consolidation of the tube-wall.

Around the outer margin of the wall occurs, as usual in sand-fulgurites, a continuous row of adhering sand-grains (Fig. 1), semi-fused and to that extent rendered white and opaque. These grains are partly rounded and from 0.2 to 0.6 mm across. All were successively examined around the thin cross-section by the usual optical methods, those of feldspar being generally recognizable by traces of cleavage, cloudy alteration, oblique extinction, lower interference-colors than those of quartz, and more or less complete biaxial interference-figures, whose negative character could often be distinguished. Out of 35 grains 23 were identified as orthoclase, the remainder as quartz. In the more angular grains wavy extinction testified to remaining mechanical stress. The indications are that the original sand was very fine and highly feldspathic, free from mica and with few ferruginous particles.

While the outer extremity of a sand-grain, so attached to the glass wall, often retains its translucency and color entirely uninjured by the electric discharge, this is sharply divided from an altered milk-white inner portion, in which the change consists mainly, with quartz, in very minute fracturing and consequent opacity. This passes, with feldspar, into a translucent border, next the glass, in which minute needles or crystallites abound, suggesting immediate devitrification after fusion. From

this border very irregular milky threads descend into the glass in a confused network, swarming with the most minute air-bubbles, approaching 1 or 2μ in diameter. In this vicinity, also, fibrous threads or streaks of glass occur, which display, between crossed nicols, feeble colors of aggregate polarization.

On reception of this fulgurite from Mr. Walker, he stated: "I have noticed in several places on the outside of the tube . . . . some very fine threads of fused quartz, like delicate spider-webs, connecting the sand-grains, as if the partly fused grains had been forced apart while still soft." This new feature in fulgurites I can confirm. The glass threads are colorless, brownish, or sometimes black; generally smooth and glistening, but occasionally roughened; more or less curved; passing from grain to grain of the adhering sand, but sometimes projecting as if broken; mostly 0.4 to 1.1^{mm} in length, and 0.015 to 0.04^{mm} in width.[1] In the glass between neighboring sand-grains many minute round holes are also perceptible[2] under a low magnifying power, apparently produced by exploded bubbles. In several cases, in the glass behind a sand-grain, there is a limpid band with faintly marked outline (best shown in photomicrograph, Fig. 2), the latter corresponding to the back contour of the sand-grain. This must mark its original position before it was jerked outward to a distance of half its diameter and the space behind filled in at once with clear glass, distinct because free from bubbles. To the force and extent of this outward jerk, in some instances, the glass threads doubtless owe their formation.

Between crossed nicols the thin section at first appears dark, like a homogeneous glass, with the exception of the ring of highly refracting sand-grains outside and occasional gleams of reflection from scattered air-vesicles. In ordinary light, under

[1] A coating of sublimed silica is often found upon the carborundum crystals manufactured in the electric furnace at Niagara Falls. The interlaced threads of quartz of which it is composed much exceed the dimensions of the natural threads above described. They differ also in the variation of diameter in a thread and in the common occurrence of a peculiar beading along many threads.

[2] MERRILL, *loc. cit.*, p. 84.

low magnifying power, a faint granulation is discernible throughout the glass. This is resolved under higher power (× 300) into an irregular, sparse to abundant distribution of crystallites through a predominant glassy base, from the margin of the lumen to the fusion-border of the sand-grains. No special concentration occurs, except in occasional richer wisps and streaks, like diffusion-streams, across minute patches of clearer glass. In general they are scattered in the same way among and near to the air-vesicles. In some cases, however, an elongated vesicle is surrounded by a band of perfectly clear glass, free from microlites, 5 to 10 μ in width, which broadens to 20 or 30 μ opposite the ends of the major axis of the vesicle. This has been plainly due to compression and extension of an original envelope of viscid glass, chilled and consolidated by proximity of the vesicle, before devitrification could take place within this envelope. But in general throughout the glass we may recognize one condition that has favored crystallization, in the influence of absorbed vapors, through the abundantly intermixed bubbles.[1]

These microlites are straight or curved, sometimes lath-shaped, less than 1 μ in length in some cloudy aggregates, but largely 3 to 13 μ, or even extend into threads, often bent or crooked, 30 or 40 μ in length. They lie in all positions and never display any fluidal arrangement,[2] though the larger number seem to be radially disposed toward the center of the fulgurite-tube. Between crossed nicols the microlites exhibit very feeble double refraction, mostly pale gray, here and there brightening into pale greenish-white of the first order. All these forms appear to represent the regeneration of feldspar. A very few margarites were also distinguished, and one spherulite

[1] As in the pumiceous glass of the fulgurite of Little Ararat III, as well as in the devitrified glass of Monte Viso, of which Rutley states that the vesicles are sometimes so closely packed that the glass is quite spongy. However, the pumiceous glass of other fulgurites has been found entirely homogeneous.

[2] In fulgurite-lumps from Florida, Merrill recognized a fluidal structure in the homogeneous glass near bubbles, "as if by sudden expansion of a steam-bubble in the plastic material" (*loc. cit.*, p. 87).

of about 3 μ diameter, made up of concentric shells, which exhibited a faint cross, remaining fixed on rotation.

This unique occurrence of devitrification in the glass of a sand-fulgurite is perhaps mainly connected with the high proportion of feldspar in the original sand. Such a chemical constitution must have approached that of the rhyolite[1] used in the experiments of Barus and Iddings, whose viscosity and whose electric conduction, when fused, were both found to exceed those of the less acid rocks, and led to the conclusion that "electric conduction increases with the degree of the acidity of the magma. . . . . Since fusibility decreases in a marked way as the composition of the magma approaches pure silica, it follows that, in a series of different magmas, electric conduction at any given temperature increases in proportion as the viscosity increases." From this it must be inferred that the more quartzose sands, when once melted by a lightning stroke, have offered the viscous medium of readiest passage to the current.

Exception has been rightly taken, however, to the assumption that the material of a fulgurite-tube was necessarily or entirely "quartz-glass."[2] The general distribution of feldspar in notable quantity through ordinary sands is a fact in favor of the suggestion of Wichmann and Harting, that the minerals of comparatively ready fusibility have served as flux and thus ended in reducing the more refractory. Particularly then in this fulgurite do we need to consider not only the relative fusibilities of feldspar and quartz, but also the relative degrees of their solvency in contact with the first formed portion of molten glass, doubtless so instantaneous in formation as to be independent of all differences in fusibility, solution, conduction or any other property of the various sand-grains.

To throw light on this question and on the variations, recorded beyond, in devitrification of such natural glasses, a

[1] Silica, 75.5 per cent.; alumna, 13.25; soda, 4.76; potassa, 2.85, etc. Heated in a platinum crucible, it melted at 1500° C., was very viscous ("a stiff paste") even at 1600°, and quite viscid at 1700°. *Am. Jour. Sci.*, Vol. XLIV (1892), pp. 242–249.

[2] See v. GÜMBEL, *loc. cit.*, and *idem*. Vol. XXXVI (1884), pp. 179–180, and criticism by A. WICHMANN.

preliminary examination was made of a specimen of artificially vitrified gneiss, with brown glassy fracture, obtained from the hearth of a limekiln at Tuckahoe, N. Y. This had been evidently thoroughly roasted and deprived of moisture but not fused (as the gneiss structure still perfectly survived, in the undisturbed parallel biotite-scales), saturated with slag from the kiln, and finally thrown out and slowly cooled upon the refuse-dump. In a thin section under the microscope, the results of the action of fused glass upon the original minerals of the gneiss were found to be as follows: a slight solvent attack upon the biotite, rendering it in part opaque, with brown haloes and cloudy wisps of iron oxide feathering out into the adjacent glass, apparently by quiet molecular diffusion; a decided but partial solution of the quartz, of which a small portion survived in angular remnants, still in place; and complete solution and disappearance of the feldspar. The main mass of the saturated rock had thus been converted into pure colorless glass, with a few coffee-colored stains, without any trace of crystallites or new stony matter, notwithstanding its slow cooling. However, globules of clear glass, about 0.5^{mm} in diameter, were abundantly interspersed, colorless like their matrix and with little adherence, since many had become loosened and removed from the surface of the thin section during the process of grinding. It was consequently inferred:

1. That minerals of acidic constitution, feldspar and quartz, may be largely carried into solution, in contact with fused glass, at a temperature below their thermal melting points.

2. That their fused products tend to cohere *in situ* in spheroidal globules, through possession of a different degree of density, viscosity and contraction on cooling, from that of the surrounding glass.

3. That the process of devitrification has been prevented in this vitrified gneiss by the peculiar constitution, probably the acidity, of the unsaturated glass, and by an insufficient period of cooling.

In the development of a sand-fulgurite by almost instantaneous

fusion, it is unlikely that any selective power could have been exerted among the sand-grains, through their slight variations in fusibility, conductivity or other property. All within a radius of a few millimeters were suddenly and completely fused, with a limitation so sharply defined, in this fulgurite, that, in any sand-grain, the quartz or feldspar may remain entirely unaltered within an interval of about 0.02^{mm} of the same material fused and again devitrified. The molten mass of its wall became a supersaturated solution of feldspar, with specially strong solvency, however, toward any external quartz-grains within its reach, through the tendency to form more acid silicate. Such action probably accounts for the increased amount of silica which has been determined in fulgurite-glass over that in the original sand in several instances.[1] In this fulgurite also the preponderance of feldspar over quartz in the attached sand-grains may possibly have become exaggerated by the slower solution of the former mineral.

The view has been advanced[2] that a selective power of fusion has been exerted by the electric current among the grains, but without regard to their fusibility: the poorer conductors (quartz-grains), offering so strong resistance as to become heated to the point of fusion, those substances which are the best conductors (iron-oxides and feldspars) escaping with least injury. It is notable, however, that it is not a good conductor but quartz only which has ever been recognized in remnants of grains inclosed in the glass of other sand-fulgurites, and that no remnants whatever are enclosed within the glass of this fulgurite, apparently because so rich in flux.

Three rock-fulgurites will now be described in the order of increasing devitrification.

[1] In a fulgurite from Union Grove, Ill., silica 91.66 per cent. in the glass to 84.83 in the sand; in another, 95.91 in the glass, to about 90 in the sand. (MERRILL, *loc. cit.*, p. 85.)

[2] MERRILL, *loc. cit.*, p. 87. Diller notes, however, in a fulgurite on hypersthene-basalt, that the sequence of alteration is according to degree of fusibility of the components of the rock, greatest in the groundmass, then hypersthene, then feldspar, and least in olivine.

II. *Fulgurite* on gneiss, near *Split Rock, Lake Champlain, New York;* specimen collected by Professor William Hallock, of Columbia University, immediately after the lightning-stroke, as described in his accompanying article. Thin sections of this granite-gneiss were prepared, one in plane parallel to and within about 0.03^{mm} of the fulguritic crust, the other in cross-section. The rock is found to present a surface somewhat dulled by weathering, and to consist, to about 70 per cent. of its volume, of feldspars, microcline, microperthitic orthoclase and a little plagioclase, besides much quartz and a small amount of magnetite, biotite, garnet, and rutile, but no trace of fulguritic glass. No undulatory extinction occurs between the nicols, as evidence of strain.

The fulgurite-pellicle is entirely superficial,[1] brittle, and with slight adherence to the rock, from 0.1 to 0.3^{mm} in thickness, nearly white, consisting chiefly of a minutely blebby hyaline crust with blistered, glistening surface, whose bubbles, rarely exceeding 0.2^{mm} in diameter, are nearly spherical but somewhat elongated normally to the surface of the rock. On careful examination of these, in a flake mounted in balsam, under a good tenth-inch immersion objective, no water of condensation could be detected in any vesicle.

Many short glass-fibers occur, sometimes with globular ends, resembling some of those in "Pele's Hair" from the crater of Kilauea, Hawaii. This white pumiceous slag is quite uniformly attached to the predominant surfaces of feldspar, though pierced by the uncovered gray grains of quartz. It is dispersed over the rather even surface of the hard gneiss in radial, somewhat dendritic forms, often many inches in length, thinning out into feathery fleeces at the margins. Wherever these pass over minute plates and seams of the dark minerals of the rock, the blebby fulgurite assume a yellow, red, brown, or black color, as a dark enamel, or in the form of tiny spherules.[2]

[1] Similar superficial films of fulgurite have been often observed, by Humboldt in Mexico, by Brun in the Alps, by Ramond on mica-schist, on limestone, and on phonolite in the Pyrenees and Auvergne.

[2] Over the fulgurite-crust on hornblende-gneiss at Mount Blanc distinct white and

The white material, when flaked off and mounted in Canada balsam, reveals a limpid glass, dispersed with very few and minute straight microlites and very rarely rhombic plates; the latter display rather bright interference-colors between crossed nicols and parallel extinction.[1] Where thinnest, the glass remains isotrope and dark, while the thicker portion, generally toward the center of the flake, glows with the greenish-white of the first order of Newton's colors; in places the color reaches the sky-blue of the second order, exactly like a thin scale of the underlying feldspar. The indications are that devitrification had begun, throughout the glass, in globulites too extremely minute for distinction, even under high magnifying power, but whose concentrated effect in depolarization becomes visible, between the crossed nicols, in the thicker parts of the flakes. The flakes of brown or colored glass, however, are found to be uniformly isotrope. It should be noted that, as the greater thickness of these flakes approaches or exceeds 0.5^{mm}, it is probable that the presence of crystallites might hardly have been recognized in a ground section of the ordinary thinness, 0.02 to 0.05^{mm}. In such an investigation plane surfaces are not indispensable, and the examination of splinters of a glass may serve an important office. Evidences of incipient devitrification, in fulgurites and other glasses, have possibly escaped detection by observers relying entirely on examination of thin sections.

The facts above described lead to the following conclusions:

1. We have here to do with different conditions from those

dark globules were dispersed: "the fused surface of each crystal solidified almost exactly *in situ*, except where sputtering of the molten matter was caused" (RUTLEY, *Quar. Jour. Geol. Soc.* (1885), pp. 152–156). The inclosed globules in the slag-saturated gneiss of Tuckahoe may represent a similar tendency to isolation.

[1] The homogeneity of glass which apparently prevailed in all fulgurites examined by the early observers led naturally to the statement in 1884 that the absence of crystallites "may be used as a means of distinguishing fulgurite from other natural glasses" (J. S. DILLER, *Am. Jour. Sci.*, Vol. XXVIII (1884), pp. 252–258). In 1889, Rutley made the first and hitherto the only record of the occurrence of devitrificatoin in a vesicular fulgurite-glass on glaucophane-schist, at Monte Viso, Cottian Alps. The crystalline forms consisted of globulites, margarites, and longulites, and even symmetrical microliths (*Quar. Jour. Geol. Soc.*, Vol. XLV (1889), pp. 60–66).

which attended the sand-fulgurite I, viz., the lessening force of a divided electric current, passing over the surface of a compact rock-mass. The effect of the electric action on this solid surface of gneiss has been more diffuse, feeble, and superficial than in the sand-fulgurite, and, in this case, confined to the feldspar.

2. The fulgurite crust has been produced almost entirely by fusion of surfaces of feldspar-grains rather than of quartz, and in small degree by that of the iron-containing minerals. The property of fusibility, rather than that of imperfect conduction, has determined the amount of attack on each grain. Each kind of glass, colorless and colored, is sharply confined to the mineral surfaces from whose fusion it originated, with little tendency to intermixture.

3. The bubbles throughout the fulgurite-crust owe their formation chiefly to expansion of air, and in part doubtless of steam, derived from moisture in the weathered surface of the rock. Their sputtering explosion has probably produced the tiny fibers over the blebby surface.

4. The surprising partial devitrification, which has instantaneously followed fusion throughout the delicate white pellicle, has been evidently facilitated by the supersaturated feldspar solution of which the molten glass almost entirely consisted, and by its consequent unstable molecular condition.

III. *Fulgurite* in augite-andesite, summit of *Lesser Ararat, Armenia.* The specimen was one of those collected by Dr. E. O. Hovey, of the American Museum of Natural History, New York.

The fulgurite material from this peak has received repeated study in the field or laboratory by successive observers. Abich[1] detected only pure glass in the fulgurite, but in such abundance that he suggested the name "fulgurite-andesite" for the material on the apex of the peak. Gustav Rose[2] also came to the same conclusion, and determined the difficult fusibility of the

[1] *Sits. Akad. Wiss. Wien*, Vol. LX (1870), I. Abth., pp. 153–161.

[2] *Zeit. d. D. geol. Ges.*, Vol. XXV (1873), pp. 112, 113.

glass on thin edges. A. Wichmann[1] made the most careful petrographic study of this and other fulgurites and distinguished this as "entirely homogeneous glass," without any alteration of the andesite at the sharply defined contact. He considered the bubbles as vapor-cavities (*dampf-poren*), and gave a clear representation of the structure of a lightning-tube in a well-drawn cross-section. The results of my own examination, which follow, differ in some important particulars.

The augite-andesite of this peak, though consisting of fresh plagioclase-feldspar, with some partly decayed augite, hornblende, orthoclase, and magnetite, is deeply disintegrated by weathering, so that, in some blocks, its grains crumble readily under pressure from one's fingers. It is also traversed, even in the most solid material, by numerous cavities and channels, a few millimeters in width, of most irregular form, crossing and connecting with each other at intervals of a few centimeters. Most of these passages, in the more decayed specimens I have examined, in the collection of Dr. Hovey, are one or two centimeters in width, and often coated by the olive-green fulgurite glass to a depth of 1 to 1.5^{mm}; some are even solidly filled up by the glass, with a cross-section of 5 to 8^{mm} in diameter or over. Other cavities of exactly the same form and size were noticed, adjoining but not connecting, which are now and appear always to have been entirely free from fulgurite. Most, if not all of these, therefore, seem to be preëxisting cavities, later occupied in many cases by fulgurite. A confirmation of this is found, by optical examination of the thin sections, in the absence of undulatory extinction in the grains of minerals adjacent to the fulgurite, *i. e.*, the lack of any indication of strain likely to have resulted from actual perforation of the rock by lightning. On the other hand, certain other specimens in the collection from the same peak are penetrated by cylindrical winding tubes,[2]

[1] *Idem.*, Vol. XXXV (1883), pp. 849–859.

[2] The approximately cylindrical form of the latter, and their curved windings, have been well represented by Rutley, from the fulgurite furrows on glaucophane-schist at Monte Viso, Cottian Alps (*loc. cit.*, plate).

lined or filled with the dark glass, which seem clearly to owe their perforation to the action of electric discharges upon more disintegrated blocks of the crumbling rock.

The glass is found to be rich in bubbles, especially toward and near the surface of the inner rock-wall, and in places even blown up into blebs and blisters. All of the smaller vesicles and most of the larger are approximately spherical. In none of these could any water of condensation be discovered under a tenth-inch objective; their contents appear to be entirely gaseous, *i. e.*, chiefly derived, in all probability, from expansion of air rather than steam. Many of the larger vesicles present a more or less elongated form, with major axis always arranged in position at right angles to the adjacent rock-wall. This distortion of vesicles in the glass of a rock-fulgurite may be always attributed, in my opinion, entirely to the reaction of pressure inward, *i. e.*, toward the lumen, which has instantaneously followed the passage of the electric discharge, mainly from expansion of the collected bubbles, partly from increased volume of the glass during fusion of the rock.

When crushed splinters of the glass are examined, though found sometimes entirely amorphous, as reported by Wichmann and others, it is also in places rich in bunches of stony matter, isolated needles (with bright interference-colors between crossed nicols and parallel extinction) and clusters of microlitic fibers, sometimes radiating around a bubble.

Again, at the line of contact between this glass and the andesite-wall, an intermediate stony layer occurs, 0.15 to 0.70^{mm} in thickness, containing a few obscure outlines of bubbles. This plainly consists of wholly devitrified glass, made up of a felt of irregularly crossing needles, fibrous curved wisps, or straight bundles, some rectangular in form, 0.08 to 0.20^{mm} in length, whose axes lie mostly parallel to the line of contact with the adjacent rock-wall. In the straight bundles an extinction-angle of about 19° is uniformly obtained, often with undulatory phase, and all offer the characteristics of orthoclase. There is a remarkable resemblance, if not identity, of these fibrous aggregates, in

form, structure, and optical character, to the artificial microlitic bundles obtained in the experiments of J. S. Diller (*loc. cit.*) by long fusion of amorphous fulgurite-glass in crucibles.

The difference of the above results from those hitherto reported from study of the fulgurite of this peak may be attributable to variation in the structure of the fulgurite, particularly in regard to devitrification, in different parts of the surface.

IV. *Fulgurite* from summit of *Central Butte, Little Missouri Buttes, Wyoming;* specimen collected by Mr. John D. Irving. This is a small fragment of phonolite, apparently from the edge of intersection between two joints, down which corner the fulgurite runs in a shining, cream-colored, slightly brownish crust, about 15^{mm} wide and 3^{mm} thick. On a fractured cross-section it shows distinct lamination parallel to the surface of contact, as if the latent structure had been developed by weathering.

The rock consists mainly of orthoclase-phenocrysts, whose idiomorphic character is obscured by fractures, imbedded in a smaller volume of granular, somewhat ochreous holocrystalline groundmass, through which needles of hornblende, plagioclase, apatite, and granules of magnetite are dispersed. Between the crossed nicols, the transparent minerals, in a thin section, generally display a decided undulatory extinction, in evidence of condition of strain.

This fulgurite exhibits under the microscope the unique character of a wholly devitrified mass, light brownish-gray, delicately laminated in cross-section (*a*, Fig. 3) by a very irregular flow-structure,[1] with interruptions and intersections of laminæ suggesting those observed in the cross-stratification of certain sand deposits. Some laminæ, especially near the contact-line (*e. g.*, just below *c'*), are bent and faulted, with ends slipped past each other. The thicker laminæ consist of very minute, colorless

[1] Compare the thin underlying coat, in which fusion is less complete, with dark fluidal banding, and which envelops numerous crystal remnants, described by Diller in the "mixed zone" of fulgurite-glass in immediate contact with basalt at Mt. Thielson (*loc. cit.*). Of this he states, it is difficult to conceive how it has been produced, "unless it is due to the repulsion of the particles among themselves."

needles, fibers, and granules, in an irregular felted mass, through which obscure circular and elliptical outlines (*b*, etc.) indicate the position of numerous original bubbles, now flattened, freed from gas, and even partly obliterated. With this darker material, evidently entirely devitrified glass, there occur frequent

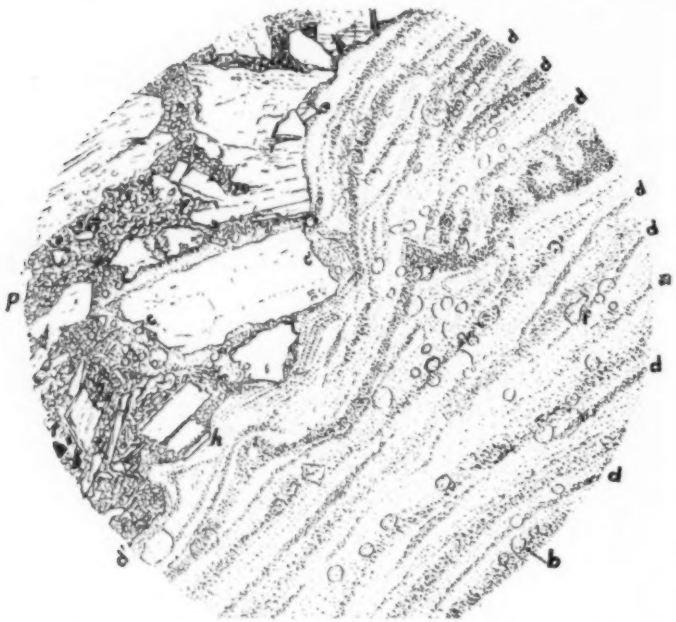

FIG. 3.— Rock-Fulgurite, Wyoming. × 50. Cross-section of contact.

alternations (*d*, *d*, etc.) of thin films of a microscopic breccia or "mylonite," shining brightly between the crossed nicols. This is composed apparently of rock-dust,[1] made up chiefly of angular splinters of feldspar; a few coarser fragments of the same are also irregularly interspersed (*f*). Along the line of contact (*d'*), the same angular dust is drawn out in streaks or gathered

[1] Apparently related to the opaque whitish layer, between the glass and rock, in the fulgurite of Monte Viso, and referred by Rutley to altered titanite.

in embayments. Its origin is well shown next the Carlsbad-twin of orthoclase (c–c'), whose outer end (c'), projecting into the fulgurite current, has been shattered into this dust to a depth of 0.1^{mm}, seemingly after the adjoining fulgurite laminæ had somewhat consolidated. This and other feldspar-grains lying along the edge of the stream, have been completely encircled by fulgurite, with an inner film of angular dust, marking the outline of the minutely shattered surface of feldspar. This micro-breccia is brought out between the crossed nicols in distinct bright stripes. The phonolite groundmass generally shows rather deeper embayments by fulgurite-attack than the feldspar-grains; but the hornblende-needles seem to lie entirely unaffected, even in immediate contact (h) with the fulgurite-stream.

It is possible that the devitrified crust which constitutes this fulgurite may be a remnant of an inner stony layer (as in Fulgurite III), from which a glass-coating may have been scaled off during weathering; but of the latter there is no evidence, and the stony crust now occurs coated by small lichens. Yet the peculiar structure of this crust, with its alternations of micro-crystalline and of micro-brecciated laminæ, signifies that devitrification has not been a secondary process due to weathering of a glass.

RÉSUMÉ.

Considerable variation appears, in the characteristics of these rock-fulgurites, from two probable causes: the variations in the electric current, in regard to volume, intensity, duration, and a probable series of successive discharges, in some cases, within the same fulgurite (IV); and the difference of the rock-material in the three specimens, gneiss, andesite, and phonolite.

In regard to the duration of a lightning-flash, it is understood not to have usually exceeded one hundred thousandth of a second (Sylvanus Thompson). The discharge is known to be oscillatory, surging back and forth, and even in many cases, like that observed by Professor Hallock, apparently persistent and continuous for some moments. Nevertheless, allowing for the

long retention of the image of the flash upon the retina, its duration is rarely likely to have much exceeded the above quoted minute interval.

The results of the electric action are of two classes, superficial and internal.

The superficial consist, in succession, of fracture of outer pellicle of exposed minerals: fusion *in situ* of the surface of more fusible grains: and development of bubbles in the enamel of molten glass from expansion of moisture and air, with frequent explosions and spattering of glass globules.

The internal results comprise the penetration of preëxisting cavities of the rock, and often the actual piercing of surface of outcrop or blocks, if softened and disintegrated by weathering, by lightning-tubes of symmetrical cross-section, as well as passage downward through fissures and joints.

This has been accompanied by fracture and fusion of pellicles over the surfaces thus traversed, especially of the more fusible minerals and groundmass; development of air- and vapor-bubbles in the molten coating; and sometimes, at least, a succession of waves, sweeping downward fused glass and rock-dust, in a series of alternating films, the oldest nearest the rock-wall and subjected to frequent dislocation.

At the moment of cessation of the electric current, there have followed reaction from the intense pressure, expansion of vesicles, and regurgitation of glass upon the surface of the rock from some filled lightning tubes;[1] explosion and disappearance of bubbles nearest the surface, distortion of many by inward relief of pressure, or general recovery of spherical form; and partial devitrification of the glass, occasionally complete, where certain favorable conditions have prevailed — probably the presence of moist air in intermixed bubbles, a supersaturated neutral glass, and an over-heated or slowly-cooling contiguous sheet of rock.

The instantaneous regeneration of feldspar only, in the form

[1] First recorded by HUMBOLDT, in rock-fulgurite on volcano of Nevada de Toluca, Mexico (*Ann. d. Ch. et d. Phys*, Vol. XIX (1821), p. 299.)

of microlites, in every instance, in the series I have examined, seems at first somewhat at variance with the conclusions of Lagorio as to the particularly difficult saturation of a molten silicate by the oxides represented in that mineral. But we have here, apparently, a far different magma from that employed in the experiments of Pelouze, artificial glass, *i. e.*, from every evidence, a supersaturated solution of feldspar in its own fused material. In such a magma-solution, a combination of silica, alumina, and alkali molecules, must find conditions highly favoring ease and rapidity in re-crystallization.

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EXPLANATION OF FIGURES

Fig. 1. Sand-Fulgurite, Poland.— Photomicrograph of cross-section, showing sharply defined outline of central lumen, the glass wall with its vesicles, and ring of dark semi-fused sand-grains, adhering to the irregular outer boundary of the fulgurite. ×10.

Fig. 2. The same.— Photomicrograph of section of part of the wall, showing forms, radial distension, and distribution of the vesicles, the smaller and darker ones still occupied by air. Several of the sand-grains appear along the outer boundary, each with its inner crescent of limpid glass. The inner dark part of a grain indicates the side which has been partly fused; the outer clear part, that which remains unaltered. ×50.

Fig. 3. Rock-Fulgurite, Central Butte, Wyoming.— Drawing of cross-section, showing line of contact (*d'*, *h*, *c'*, *e*) between phonolite, *p*, and fulgurite, *a*.

b. Obscure flattened vesicles.

c-c'. Carlsbad twin of orthoclase, with shattered ends, surrounded by feldspar-dust and devitrified glass, enclosing a few bubbles.

d, *d*, *d*. Films of rock-dust, alternating with laminæ of devitrified glass.

d'. Film of rock-dust along the contact.

e. Projecting corner of feldspar-grain, shattered by the electric current.

f, etc. Feldspar fragments scattered through the fulgurite.

h. Green hornblende needle, unaffected by the fulgurite-stream. ×50.

PHYSIOGRAPHY OF THE BOSTON MOUNTAINS, ARKANSAS[1]

THE highlands of Arkansas lie in the northwestern part of the state, and comprise about half its area. They are divided, physiographically, into a north and a south part by the valley of the Arkansas River. They are also divided structurally into the same parts, the former being a region of horizontally-bedded rocks, somewhat disturbed by faulting and folding, while the latter, known as the Ouachita Mountains, is distinctly a folded region.

This northern division of the Arkansas highlands, with its westward extension into Indian Territory, constitutes the southern part of the Ozark region.[2] In Arkansas, it is divided into a low and a high part, the former extending northward into Missouri, and passing, along its southern border, into the latter, by an irregular but bold escarpment from 500 to 1000 feet high.

It is this latter region that is known in Arkansas as the Boston Mountains. Including that part which lies in Indian Territory, its total length is about 215 miles, about 170 of which is in Arkansas. Its average width approximates 35 miles. On the south, it passes into the valley of the Arkansas River by steep slopes, though less precipitous than those on the north.

These mountains are by far the highest part of the Ozark region as well as the most picturesque. Their highest point, so far as determined, is some miles east of the town of Winslow, on the St. Louis and San Francisco railway, where the altitude is 2,250 feet.[3] From this region of highest elevation, they

[1] Read before Section E of the American Association for the Advancement of Science at the Denver meeting, August 1901.

[2] The Ouachita Mountains have been included by some writers with the Ozarks; but because of the great structural and topographic differences in the two regions, to say nothing of the probable historic differences, this is manifestly wrong.

[3] Topographic map United States Geological Survey, Winslow quadrangle.

FIG. 1.—Photo from Branner's relief map of Arkansas.

gradually fall off to the east, sinking below the Tertiary deposits just west of the St. Louis, Iron Mountain and Southern railway and south of White River; also from this region of highest elevation, they fall off westward to the Grand River in Indian Territory.[1] It will be seen that the east-west line along the crest of these mountains forms a gentle arch in the middle. Structurally, in the western part of Arkansas, these mountains are a broad, flat anticline, the strike of which is east and west. According to the geologists of the Arkansas Geological Survey, it appears that the extreme eastern part of the region is monoclinal in structure, with the dip to the south.[2]

With the exception of the Illinois River in the western part of the state, the drainage of the region is northward and eastward into White River, and southward into the Arkansas. The direction of the streams has been determined by the slopes incident to the uplift, modified in some cases by faulting and flexuring. The effect of the latter upon Little Red River and neighboring streams has already been noted by Professors Newsom and Branner.[3] The westward course of the Mulberry River has been determined by a fault. Detailed work of the region would doubtless disclose numerous other similar examples.

The drainage of the region is that intermediate between youth and maturity. The streams are vigorous, and have completely dissected the plateau by the formation of gorges from 500 to 1000 feet deep, thus producing a very rugged topography over the whole region. Between these gorges the slopes often meet, forming more or less rounded hills; but more frequently the intervening area is occupied by flat-topped, sandstone-capped hills of limited extent.

The tributaries of both the Arkansas and the White rivers have worked their way back to, and in many cases, far beyond

[1] Dr. N. F. Drake, in *Proc. of the Am. Phil. Soc.*, Vol. XXXVI, No. 156, p. 332.

[2] Newsom and Branner, "The Red River and Clinton monoclines, Arkansas," *Am. Geologist*, Vol. XX, July 1897, pp. 1–13.

R. A. F. Penrose, Jr., *Ark. Geolog. Surv.*, Vol. I, 1890; section with pocket map.

[3] *Loc. cit.*

the original water divide of the plateau, making the water divide as it now exists, a very zigzag line. In the western part of the state, the south-flowing streams are the stronger, and as a rule are robbing the White River basin of territory in this locality. Further east, in the middle portion of the region, the north-flowing streams are the stronger, and seem to be encroaching upon the drainage area of the Arkansas, while in the eastern part, the south-flowing streams head very near the north escarpment of the plateau.

The rocks of the region are mainly unmetamorphosed sandstones and shales, those at the base being of Lower Carboniferous age, and those at the top belonging to the Coal-measure series. These alternating hard and soft rocks have produced the terraces on the hill slopes, which are so characteristic of dissected regions of horizontal strata. As these terraces are often of considerable width, and are favorable horizons for springs, they are inviting to the farmer, and can be located miles away by the small farms on the mountain sides.

The low region to the north of the Boston Mountains is one of great denudation. From its northeastern part, all the rocks have been removed above the Ordovician, leaving those exposed at the surface. West and south of this is a region from which the Upper Carboniferous rocks have been removed, leaving those of Lower Carboniferous age at the surface. Standing up prominently on the latter are numerous hills of circumdenudation, composed of remnants of the horizontal strata of the Boston Mountains, and serving as living witnesses to their former extent. The height of these outliers very closely approximates that of the plateau of which they were formerly a part. This uniformity in height between the various parts of the dissected Boston plateau and its outliers suggests a peneplain, and herein lies the physiographic problem of the region.

In a region of folded or inclined strata the determination of a peneplain becomes a question of comparative ease, for in those cases denudation will have reduced both hard and soft strata to practically the same level, the peneplain intersecting

strata of all degrees of hardness. But in the case of horizontal strata undergoing base-leveling, the conditions are quite different, for then the peneplain conforms to the hard stratum or strata that happen to be near sea level. If such a region be subsequently elevated, the streams are revived, the region dissected, and the former peneplain represented by the tops of the hills, which would still be capped by the hard strata that were conformable with the peneplain before the region was elevated. Now this is exactly the structural and topographic conditions of the Boston Mountains and their outliers. But it happens that these are also the structural and topographic conditions that would prevail in a region of horizontal strata that has been elevated from beneath the ocean and is undergoing the process of base-leveling for the first time. So the problem presents itself as to which condition prevails in the Boston Mountains, and unfortunately criteria for its solution are largely if not wholly wanting.

Ordinarily, for the determination of a peneplain we look to the streams. In such cases, as is well known, the streams are winding, and flow in more or less steep-sided, symmetrical valleys, which are themselves cut down in wider valleys. In the Boston Mountains there is no such evidence of a peneplain. The streams of the region are all young, with the characteristic steep-sided gorges of such streams. So far as the writer has been able to observe, there is nothing in the region indicating an uplift since the present streams came into existence. Their valleys are relatively wide at their mouths, and gradually decrease in width back to their sources, as would be expected of streams cutting into a plateau of horizontal strata. The slopes are undisturbed by terraces, excepting such as those mentioned above, which are due to structure. Along the southern base, the oldest of the streams have reached the temporary base-level of the Arkansas River, and meander somewhat, but none of them to any great extent.

It follows that evidence of a former base-leveling, if there be such, must be looked for elsewhere than in the streams. A

recent writer[1] claims that the tops of the Boston Mountains represent a peneplain, and cites as evidence the fact that they correspond very closely in height with the Ouachita Mountains south of the Arkansas valley. This evidence is given on the assumption that the rather uniform height of these mountains represents a peneplain; but this is a hypothesis far from being established. Mr. L. S. Griswold, in his work on the novaculite region of Arkansas, encountered the problem of the nonconformance of some of the main streams of the region to the structure and topography, to account for which he presents the theory of a post-Carboniferous base-level, on which was subsequently deposited Cretaceous strata.[2] If the present writer correctly interprets Mr. Griswold, he believes the south-flowing streams, which form water-gaps in some of the highest mountains of the region, are superimposed streams, their courses having been determined by the slope of the Cretaceous area after elevation. Mr. Griswold does not claim that the evidence of this is conclusive. It is the opinion of the present writer, from somewhat limited observation, that the even crests of the Ouachita Mountains are due to structural and lithological conditions and not to base-leveling. But were it established that they represent a peneplain, the fact that the Boston Mountains closely agree with them in height does not argue a peneplain for the latter. The one is a folded area, and the other an area of horizontal rocks (Fig. 2). Erosion in the one has resulted in wide, anticlinal valleys through which flow sluggish streams, while erosion in the other is in its early stages. It would seem to follow that the time of elevation of the one region is far antecedent to that of the other, and consequently the correspondence in height between the two only accidental.

If, however, we look to the north of the Boston Mountains, we find conditions which seem to throw some light upon the subject. As has already been said, this is a region of great denudation. Its general elevation is from 700 to 1000 feet

[1] O. H. HERSHEY, *Am. Geologist*, Vol. XXVII, No. 1, pp. 25 *et seq.*

[2] *Ark. Geol. Surv.*, 1890, Vol. III, pp. 220.

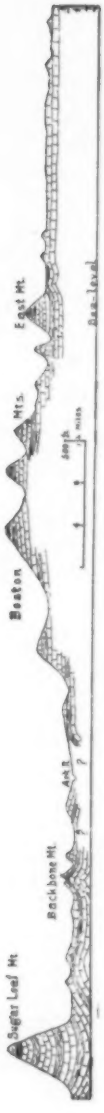

FIG. 2.—North-south section of the Boston Mountains and adjacent regions, near Arkansas-Indian Territory line.

lower than that of the Boston Mountains. Its streams are mature, the valleys comparatively wide, and the topography in general presents the aspect of much greater age than that of the Boston Mountains. Professor C. F. Marbut, in discussing that part of this region which lies in Missouri,[1] claims that it was base-leveled in early Tertiary times, and the present cycle of erosion was instituted by an elevation which dates from middle or late Tertiary times. Be that as it may, the question as to whether the region to the north of the Boston Mountains ever suffered denudation to the extent of base-leveling does not particularly concern us here. The fact of interest is that the denudation of the extensive region to the north has been very great and the topography is old, while that of the Boston Mountains is limited and the topography young.

It would appear that this difference in topography cannot be attributed to the massive beds of sandstone at the top of the Boston Mountains, for these same beds, while they have doubtless had a great deal to do with preserving the region, formerly extended over much if not all the denudated area to the north. Besides, if we attribute the preservation of these mountains to the character of the rocks composing them, we are encountered by the question as to why erosion has been so extensive to the north of the region, removing the rocks over a large area, leaving only here and there hills or circumdenudation, while in the southern part adjacent to the Arkansas valley it has scarcely begun.

I am able to account for the great difference in the stages of erosion in the two regions only by conceiving the Boston Mountain area to have been at a lower elevation than the area to the north during

[1] *Mo. Geol. Surv.*, Vol. X, pp. 27–29.

the time the extensive denudation was going on over the latter. So low must it have stood that the strata now composing their summits suffered but little erosion, while the same beds extending northward suffered much because of their greater height. If this be true, the actual amount of degradation suffered by the Boston Mountain region is indeterminable; but as there was more or less of it, and the region stood at a low level, it would be considered a peneplain. The elevation, which must have occurred in late Tertiary or in post-Tertiary time, was greatest along the present east-west axis of the plateau, gradually decreasing to the northward, and changing the region from a low, monotonous plain to a plateau approximating 2,500 feet in height, greatly modifying the former drainage and instituting that of the present.

Aside from the difference in topography between the region under discussion and the one to the north, the writer cannot at present claim very great support for the idea herein presented. There are, however, some other facts that seem to lend the hypothesis support. (1) The region being on the border of the Ozark uplift, it is probable that during the greater part of its history it lay at a low level and consequently suffered comparatively little from erosion. (2) The outliers of the Boston Mountains to the north are as a rule lower than the main plateau, though capped by the same rocks, thus indicating an axis of elevation to the south of the outliers. (3) The eastward course of White River and its tributaries may be due to their having been diverted from what would seem a more natural southern course, at the time of the uplift.

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THE DISCOVERY OF A NEW FOSSIL TAPIR IN OREGON

A FAIRLY complete phylogenetic series of early Miocene tapirs has been made known to science through the researches of Messrs. Wortman,[1] Earle, and Hatcher.[2] Between these ancestral forms, referable to the genus *Protapirus*, and the living species is a gap in the line of descent which has remained unbridged until the fortunate discovery of the form presently to be described.

Our knowledge of the tapir phylum since the White River epoch may be summarized in a few words. In 1873, Dr. Joseph Leidy[3] described under the name *Lophiodon oregonensis*, two imperfect superior molars obtained by Professor Thomas Condon at Bridge Creek, Oregon. Two species have been described by Professor Marsh,[4] which he refers to the genus *Tapiravus: T. rarus* from the Loup Fork of the Rocky Mountains, and *Tapiravus validus* from the Miocene of New Jersey. From the brevity of the description and the lack of figures, these species are practically indeterminate. Remains of tapirs belonging to the existing genus are known from the Quaternary gravels of California,[5] and have been described from several localities in the eastern states.

During the summer of 1900, Professor John C. Merriam and Mr. V. C. Osmont, of the University of California, while collecting in the fossil beds of the John Day valley, Oregon, obtained

[1] J. L. WORTMAN and C. EARLE, "Ancestors of the Tapir from the Lower Miocene of Dakota," *Bull. Am. Mus. Nat. Hist.*, Vol. V, p. 159.

[2] J. B. HATCHER, "Recent and Fossil Tapirs," *Am. Jour. Sci.*, 4th ser., Vol. I, p. 161, 1896.

[3] U. S. Geol. Surv. of the Territories, Vol. I, p. 219, Pl. II, Fig. 1.

[4] O. C. MARSH, *Am. Jour. Sci.*, Vol. XIV, p. 252, 1877.

[5] J. D. WHITNEY, "Aurif. Gravels," *Mem. Mus. Comp. Zoöl.*, Harvard, Vol. VI, p. 250; W. P. BLAKE, *Am. Jour. Sci.* Vol. XLV, p. 381.

the bones which form the subject of the following discussion. The remains are from the Promerycochœrus horizon (Upper John Day) exposed on the bank of the John Day river, beneath the Columbia basalt, to the west of Spray post-office, Wheeler county, Oregon. In a recent paper,[1] Professor Merriam named the beds of the Upper John Day the Paracotylops beds, basing the name on the new genus *Paracotylops*, proposed in the same paper by Dr. W. D. Matthew for the typical Oreodonts of this horizon. In the numbers of the *American Journal of Science* for last December and January, a paper by Mr. E. Douglass appeared in which these Oreodonts were provisionally named *Promerycochœrus*. Neither Professor Merriam nor Dr. Matthew read this article before the publication of Professor Merriam's paper, and consequently did not notice the new name. It now appears that *Promerycochœrus* should be retained as a generic name, and consequently, at Professor Merriam's suggestion, the name of the beds of the upper division has been changed from Paracotylops to Promerycochœrus beds.

The type specimen (No. M 934, Univ. of Cal. Pal. Mus.) comprises several superior incisors; the lower jaw lacking the posterior portion, with representatives of all the inferior dentition excepting the canines and the third molar; the proximal portion of the left humerus; the left radius; the scaphoid, lunar, magnum, and unciform of the right carpus; three metacarpals of the same side, and a few phalanges. The bones are those of a single individual of a new species of the genus *Protapirus*, for which the name *Protapirus robustus* is proposed. It is considerably larger than any of the White River species of *Protapirus*, and would approximate in size the most specialized living tapir, *Elasmognathus bairdii*. The lower jaw is represented about one-half natural size in Fig. 1. The symphysial region was found in place, imbedded in a buff colored tuff so characteristic of the Upper John Day beds that the expression "buff beds" was used as a convenient field term for this horizon. The other bones lay loose on the surface in the immediate vicinity.

[1] "A Contribution to the Geology of the John Day Basin," *Bull. Dept. Geol., U. of Cal.*, Vol. II, No. 9, p. 296; JOUR. GEOL., Jan.-Feb., 1901, p. 72.

The dentition.—The superior incisors are larger than the corresponding teeth in *Elasmognathus bairdii*. The inferior incisors are slightly smaller than the superior. Both series have the crowns somewhat cupped, especially so in the superior incisors. The first and second inferior incisors are of equal size, while the third is two-thirds as large as those preceding it. The crowns of both canines are broken off, but the diameters of their roots, measured on the alveolar borders, are greater than the corresponding parts of the larger incisors. A long diastema succeeds the canines. The premolars have their anterior cusps united into transverse ridges, slightly notched at the summit. In all

FIG. 1.

except the second premolar, the ridges are perpendicular to the long axis of the jaw. They are equally developed on the third and fourth premolars. Posterior cross crests are not developed on any of the premolars. In the second premolar, the protoconid is larger than the deuteroconid and is situated farther forward than the latter. In the succeeding premolars, these cusps are of the same size and are situated directly opposite each other. The tetartoconid of the premolars is smaller than the metaconid. The latter cusp is united with the inner side of the base of the protoconid by a ridge. This structure is also found in the molars, all of which have two cross crests. The posterior crest in the first and second molars is somewhat oblique to the axis of the jaw. The third molar is too imperfectly preserved to describe. Anterior and posterior cingula are present on all the molars and premolars. Traces of an external cingulum are found at the outer end of the transverse valley in all except the second premolar. In this tooth the paraconid is very large, uniting by a ridge with the protoconid. In the remaining premolars the paraconid is replaced by a style rising but little above the level of the anterior cingulum.

The jaw.—The inferior border of the jaw is parallel with the alveolar border. The symphysial portion rises at a low angle, much less than in the tapir. The flatness of this angle is perhaps due in part to a slight amount of crushing which the specimen has sustained. The posterior border of the mental foramen is directly below the anterior border of the second premolar.

The fore limb.—The humerus and radius have about the same shape as in the tapir. The deltoid ridge of the former is broken off, so that it is impossible to say whether it was hooked or not. The shaft of the radius is more strongly curved than the corresponding element in *Protapirus validus* as figured by Hatcher,[1] but a part of the curvature may be due to distortion. The carpus does not call for special description, not differing materially from that of *Protapirus obliquidens*. W. & E. The anterior contact of the lunar and magnum is still small, as in the White River species. There were four digits in the manus, the length of metacarpals III, IV, and V being about the same as in *E. bairdii*, but less robust. In shape they correspond closely with the metacarpals of the latter, except that the proximal portion of the fifth is inclined at a greater angle to the shaft of the bone than in the living form. The phalanges, which are of the second row, are shorter and less robust than those of the tapir.

Phylogenetic position.—The remains just described indicate an animal much larger than any of the White River species of the same genus. The structure of the molars and premolars suggests *Protapirus validus* as a probable ancestor. There are, however, several differences. In addition to the considerable difference in size, the third premolar of *P. robustus* has the anterior cross crest vertical to the long axis of the jaw, while in *P. validus* it is somewhat oblique. The diastema, as in *P. validus*, is shorter than in *Elasmognathus*, while the mental foramen has moved slightly posterior to the position it occupies in the White River ancestor. Gradations between the two types probably occur among the as yet unknown tapirs of the Lower and Middle John Day.

[1] *Loc. cit.*, p. 167, Fig. 1.

MEASUREMENTS OF PROTAPIRUS ROBUSTUS

Length of inferior molar-premolar series	128 to 130 mm
Length of inferior premolar series	60
Length of inferior molar series (approximate)	70
Length of diastema	46
Length of symphysis measured on lower side	71
Depth of ramus below alveolus of Pm. 2	48
Depth of ramus below alveolus of Pm. 4	49
Depth of ramus below alveolus of M. 3	43+
Length of radius	181
Breadth of proximal end of radius	45
Breadth of distal end of radius	39

In this connection, may be mentioned a second specimen, (No. M 1525 University of California Pal. Museum), representing probably another new species, obtained by the writer in the uppermost beds of the John Day system, on Johnson Creek, Grant county, Oregon. The horizon is considerably higher than that from which *Protapirus robustus* was obtained, and appears to be faunally distinct. It is characterized by the remains of numerous individuals of a camel belonging to the genus *Protomeryx* and by a rodent generically new. The tapir remains are of a young animal and are not complete enough to characterize specifically. They comprise fragments of a jaw with which three incisors and the second inferior premolar are preserved. The two large incisors, apparently the inferior median pair, are two-thirds as large as the corresponding teeth in *P. robustus*. They are spatulate in shape and slightly cupped. The anterior face is marked by delicate growth lines. The third incisor is an exceedingly small tooth with the crown $3\frac{1}{2}$ mm broad. Imperfect preservation of the symphysial region renders it impossible to make any statement regarding the canine. The second premolar of the right side is the only one of the cheek teeth perfectly preserved. This tooth is entirely unworn, and was just appearing through the gums at the time of the animal's death. In this tooth, the tetartoconid is much larger than in *P. robustus* and the junction of the metaconid with the tetartoconid is much more complete, forming a cross crest but slightly notched. A ridge

joins the former cusp with the middle of the anterior cross crest. The protoconid is considerably anterior to the deuteroconid and as in *P. robustus* is united with the paraconid by a ridge. The anterior cross crest is sharply notched, but this structure would probably assume the character of the anterior cross crest in *P. robustus* with the wearing down of the deuterocone by use. External cingula appear at the outer margin of the median valley and on the external side of the paraconid. A posterior cingulum is also developed.

MEASUREMENTS

Width of the crown of first inferior incisor	$9\frac{1}{2}$ mm
Width of the crown of third inferior incisor	$3\frac{1}{2}$
Length of the first premolar crown, antero-posteriorly	$15\frac{1}{2}$

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THE FORMATION AS THE BASIS FOR GEOLOGIC MAPPING

In a recent number of this Journal Mr. Bailey Willis, in a paper on "Individuals of Stratigraphic Classification," has restated and rediscussed the problem which must be solved before cartographic work of any magnitude can be planned. This problem involves a careful consideration of the relative weights to be assigned, in any system of classification to be used on geologic maps, to faunal, lithologic, and chronologic (successional) characters. Mr. Willis discusses the question in its various aspects, and his final decision is that the lithologic unit (formation) is best adapted to the requirements of the cartographer.

While agreeing, in the main, with the conclusions reached by Mr. Willis, it seems desirable to call attention to certain arguments, not specifically mentioned by him, which may be adduced in support of those conclusions; and, further, to examine the results of the application of the proposed system of classification to some particular cases of interest.

Before commencing the discussion of this question I wish to acknowledge my indebtedness to Dr. F. J. H. Merrill, director of the New York State Museum, who has greatly aided me, with both criticism and advice, during the preparation of this paper.

THE NECESSITY FOR UNIFORMITY

Though the formation, defined primarily by lithologic characters, was officially adopted in 1889 as the cartographic unit of the United States Geological Survey, in practice it has not entirely superseded other units of classification. Great variety exists in the practice of the various state geological surveys, as is indicated by their official maps; and greater variety, as might indeed be expected, in unofficial maps accompanying papers on

areal geology, even though the authors be connected with surveys whose official practice is uniform.

In considering the representation on a map of the geological features of a small, isolated area, the question of the taxonomic unit to be employed is usually of minor importance; though even in this case, as shown later, there would seem to be good reasons for the adoption of the lithologic individual as this unit. The interest attaching to this question increases directly with the size of the area to be mapped; and the problem becomes of paramount importance when the independent work of several geologists is to be combined, as in the compilation of a geologic map of an entire state or other large area.

In view of these facts, and of the slow but steady spread of the geologic-folio work carried on by the United States Geological Survey, it would seem necessary that the various local surveys should adopt the same general system of classification for map work. In the present state of our knowledge, detailed chronologic classification, the unit for which would be the epoch[1] of earth-history, is impossible; and the problem of unification is therefore resolved into the choice between two alternative systems, based respectively upon biologic and lithologic characters. In the opinion of the writer a geologic survey, whether state or national, can best accomplish the work for which it is intended by adopting as its cartographic and taxonomic unit the formation, defined as a lithologic individual.

THE RELATIVE SCIENTIFIC VALUES OF BIOLOGIC AND LITHOLOGIC UNITS

For the purposes of the present discussion it is necessary to point out that our knowledge of the two histories (*i. e.*, of sedimentation and of life), so far as that knowledge can be expressed on maps, is decidedly different in grade. The present phase of earth-history may be examined for a determination of the truth of this statement. We can map without difficulty the topographic features of the earth; and the possible accuracy and

[1] The word epoch is here used in an entirely general sense.

precision of such mapping is limited only by the consideration of expense. Moreover, we are able in most cases to discuss topographic features in terms of causality.

With regard to the present biologic condition of the earth our knowledge is much less definite. Mapping the distribution of existing faunas or floras is not practicable in the present state of our knowledge of biotic[1] distribution, except in a very general way; anything like a detailed map is impossible. This condition is due partly to the expense of collecting sufficient data on the range of the different species of plants and animals. Most of the difficulty, however, arises from the fact that the principles underlying and regulating animal and plant distribution are still far from being well understood, though of late years great advances have been made in that direction.

If our knowledge is thus imperfect with regard to the existing biota,[2] our knowledge of the facts and causes of its distribution during past ages is still less definite. It is noteworthy that two of the most successful attempts[3] to account for biotic distribution and evolution in periods antedating the present have been the work of geologists specializing in physiographic work, a branch which necessitates lithologic rather than biologic discriminations.

Obviously, the paleontologic record must always be more defective than the lithologic; for fossils are not always found where rocks are exposed. In addition to gaps occurring because of local lack of fossils, two periods are particularly incapable of being treated on a biologic basis; one immensely long period at the commencement of geologic history, and one short but highly important period immediately preceding the beginning of written history.

With regard to the relative values of the biologic and lithologic units as measures of absolute time, the case is somewhat

[1] Biota = the sum of the fauna and flora of a region. *Cf.* STEJNEGER, *American Naturalist*, February 1901, p. 89.

[2] T. C. CHAMBERLIN, "Systematic Source of Evolution of Provincial Faunas," JOURN. GEOL., VI, pp. 597–608, 1898. J. B. WOODWORTH, "Relation between Base-leveling and Organic Evolution," *American Geologist*, XIV, pp. 209–235, 1894.

in favor of the latter unit; for the relation existing between time taken in deposition and thickness of formation is much more traceable than that between extent of variation and time taken in evolution.

In considering the adoption of a basis for geologic mapping the biologic unit has, therefore, no antecedent claim to special consideration on scientific grounds; and its value can be compared directly with that of the lithologic unit in regard to their relative practicability and utility.

THE RELATIVE PRACTICABILITY OF THE TWO SYSTEMS

A lithologic unit can usually be so described and defined as to be readily identified by any future worker in the same or an adjoining area through which the formation extends.

It should also be noted that all geologists substantially agree upon the use of the terms in which lithologic individuals are defined, and will consequently agree closely in their valuation of any series. "Limestone," "sandstone," "slate," "conglomerate," all have fairly definite meanings, and it is improbable that terms such as these are used in very different senses by different geologists. The biologic unit, on the other hand, is rarely capable of being so described or defined as to be acceptable to all paleontologists. The difference is that the lithologic individual is a fact; the biotic individual, as commonly described, is a fact plus an interpretation; and while there may be substantial agreement as to the facts in any given case, it is but rarely that the interpretations will coincide.

The Hudson formation in the vicinity of Albany, N. Y., presents an excellent example of some of the practical difficulties encountered in attempting to represent faunal distinctions on a map; and a brief sketch of the conditions may be of interest in the present connection.

The "Hudson River group" of the earlier classifications—the "Hudson formation" of the present system of nomenclature—comprises in the central portion of the Hudson River valley, where it is best developed and exhibited, a thick and extensive

series of shales, with interbedded sandstones and occasional thin beds or lenses of limestone. This series is well shown along the banks of the Hudson River, extending almost uninterruptedly from Fort Edward to Cornwall. Faunal differences justify the paleontological division of the "group" into four stages, of which the two lower carry a fauna which would correlate them with the Trenton (using that term in its paleontological significance), while the other two represent respectively the Utica and Lorraine beds of the Mohawk valley. This division into stages, however, is and must be largely theoretical, for it cannot well be carried out in practice on a map. Fossils, especially of species which can be regarded as of taxonomic importance, are neither profusely nor regularly distributed throughout the beds in question. Outcrops carrying characteristic fossils are too few and far between to warrant mapping the area, on a paleontological basis, on any large scale. The lithologic differences which occur in the group have no stratigraphic or cartographic value, being too slight and variable to admit of separate representation on a map.

Modern geologic mapping, especially if the base of the map is to be a topographic atlas sheet, in order to make adequate returns for the expense involved, must be accurate within the limit fixed by the scale of the map.

The production of a geologic map is necessarily accomplished by the exercise of two functions, observation and inference. Observation involves the location of outcrops and lithologic boundaries with reference to fixed points in the control of the map, and is therefore purely a matter of engineering. The exercise of the function of inference is necessary in order to indicate the positions of boundaries concealed by superficial material. Inferences in relation to such matters are dependent for their accuracy on the training and judgment of the geologist; his appreciation of the relations existing between structure and topography, and his knowledge of the geometric effects of dip, pitch, etc., in determining the position, both horizontal and vertical, of a concealed boundary line.

Other things being equal, the determination of the altitude and geographic position of a given point is dependent upon the engineering skill of the observer; and the cartographic unit to be employed does not seriously affect this phase of the work of mapping. With regard to inference, however, this is not the case. No necessary relation exists between a biologic unit and the topography or structure of the area in which it occurs. On the other hand, topography, structure, and the lithologic unit are in general closely related. Recognition of these relations makes it possible to draw inferences concerning the position of the concealed boundary of a lithologic unit from the geologic structure and topography of the area discussed.

THE RELATIVE UTILITY OF LITHOLOGIC AND BIOLOGIC MAPS

A lithologic unit is normally also an economic unit, whereas there is no necessary relation between the biologic unit and the economic importance, or lack of importance, of the rocks containing a given biota. Though this argument may be regarded by some as of less weight than one based on purely scientific grounds, it is nevertheless valid, as applied to the question under discussion. It should not be forgotten that no geologic survey has ever been instituted, save for economic reasons; that the chief argument that can be used to obtain state support for such surveys is the direct economic return to the public; and that simple justice demands, in return for this support, that the geologic results obtained be placed in such a form as to be of the greatest possible use to that public.

The lithologic unit is also generally related to geographic forms in a very definite manner, as well as to geologic structure. The effects of these relations upon the actual work of mapping have been discussed. Here it is only necessary to point out that both topography and structure are often of economic importance. A map based on a unit which bears some definite relation to them is, therefore, of greater value from an economic standpoint than if the unit be one not so related.

THE DIFFICULTIES IN MAPPING ON THE LITHOLOGIC BASIS

Difficulties will certainly be encountered in mapping any large area on a lithologic basis, but these difficulties will arise rather from differences in the interpretation of the rules for the nomenclature of the units than from any defects in the system itself. Certain cases of interest in this connection are discussed below:

Case 1.—The case is that cited first by Mr. Willis (p. 563). A shale passes along the strike into a limestone which retains identical stratigraphic associations. "Being exactly continuous stratigraphic units, they should retain the same geographic name on grounds of convenience and simplicity." Considered as a stratigraphic unit, the two would be discussed as the "X" formation. In order to preserve all the advantages of the lithologic system of classification, however, the limestone phase should be differentiated, in both discussion and mapping, from the shale phase; their respective names being then the "X" limestone and the "X" shale. The term "phase" seems to serve a useful purpose in this connection, and the present writer, therefore, proposes it for use in marking variations of sedimentation or of metamorphism within the stratigraphic unit. When used later in this paper, it will be with this restricted and definite meaning.

This case is illustrated excellently in New York state and western New England, in this example the phases representing variations in metamorphism. The Hudson shales of the central part of New York state are progressively metamorphosed to the eastward, becoming first slates and then mica-schists. The schistose phase has been called, in Massachusetts, the "Berkshire schist;" in southeastern New York, by Merrill, the "Manhattan schist," while Dale has described the intermediate phases as "Hudson slates." Throughout the entire area, though differing thus in character because of variations in metamorphic action, the rocks are essentially continuous stratigraphically; and recognition of this fact has led to the recent proposition to eliminate the names Berkshire and Manhattan, and denote the

various phases of the Hudson formation by the term "Hudson shale," "Hudson slate," "Hudson schist." This system of nomenclature, while recognizing the essential stratigrapic equivalence and continuity of the various phases, allows these phases to be discriminated from each other on lithologic grounds. On maps this discrimination can best be shown by the use of some of the various overprints used to denote metamorphism.

Case 2.—The second case noted by Mrs. Willis is that of a "shale grading into a limestone with prolonged overlap, so that the two rocks must be discriminated in one area. Not only are they lithologically different but they have different stratigraphic associations, and they should receive distinct" formational names. As noted under the preceding case, this is the condition which usually obtains where there is a horizontal gradation in character of sedimentation. The writer believes that Mr. Willis has here suggested the proper treatment of the question, but wishes to point out an actual case of some areal importance in which this ruling has not been followed.

The example occurs in the northwestern part of Massachusetts. To the west of Hoosac Mountain, the Cambrian quartzite is overlaid by Stockbridge limestone and this in turn by Hudson (Berkshire) schist; on and east of the mountain the limestone does not appear. It has been generally assumed that the schist of the mountain represented both the Berkshire schist and the Stockbridge limestone, and the name "Hoosac schist" has been applied to it in several publications.

What the writer wishes to point out is that, under the proposed rules, the name at present used for one of those formations would seem to be untenable. For, if the eastern (Hoosac) schist represents both the Berkshire schist and Stockbridge limestone, the case becomes the same as 2, and in that case all the schist should be called Berkshire and all the limestone Stockbridge. If the transition be considered sudden, then it exhibits a slight modification of case 3, and still all the schist is Berkshire schist and all the limestone Stockbridge limestone. If the relations at Hoosac Mountain be referable to overlap,

then it is obvious that the Hoosac schist is simply an equivalent of the Berkshire schist, while none of the Stockbridge limestone is represented by any of the schist east of the mountain. On any hypothesis, therefore, the formation name "Hoosac schist" is apparently untenable.

Case 3.—The third example cited by Mr. Willis is that of a shale which varies horizontally in such a manner as to become differentiated into several superposed members, one of which is a similar shale, the others limestone or sandstone. His decision is that in such a case all the shale can be given the same formation name, while the new members (limestone, sandstone, etc.), are to be given distinctive names; but that, in case it be desirable to refer to the group as a whole in some area where it is thus differentiated into several members, the geographic name applied to the shale alone cannot be applied to the entire group.

The last three cases cited by Mr. Willis present instances of subordinate parts or local developments (of the lithologic unit) which, though too small for mapping, are of interest in discussion. To such sections of the unit the terms "member" or "lens" may be applied. This method of treatment and terminology, if followed strictly and uniformly, would seem to be entirely satisfactory.

SUMMARY.

It will be seen that the essential character of the proposed unit is that it is uniform, or uniformly variable, in lithologic character. Both its upper and lower limits and its lateral boundaries will therefore by marked by lithologic differences. So long as the formation is geographically continuous, no other criterion is necessary or even admissible.

In the case of discontinuities in outcrop, caused by the presence of bodies of water, or of intervening areas of other rocks or superficial deposits, the question will arise as to the treatment in mapping of two distinct bodies of rock, identical lithologically. In this case the aid of stratigraphic association or contained fossils may be invoked.

In regard to sharpness of definition, ease and accuracy of

mapping, and utility of the resulting maps, the lithologic unit would seem to leave little to be desired. Difficulties arising from diverse interpretations of the rules for its discrimination can be overcome with little trouble. A more serious difficulty, however, is to be encountered in regard to the question of the geographic names to be given the units. It is not sufficient to say that the rules of priority will determine the name to be used, even if those rules be re-formulated with special regard to this particular question. The difficulty to which the writer alludes can almost be said to be inherent in the definition of the unit and to be avoidable only by giving a very free interpretation of that definition. It arises when two or more geologists, who commenced work in more or less widely separated areas, have carried areal mapping to a junction. Identical formations will then bear different names on adjoining folios. In regions whose geology is fairly well known, identity of nomenclature can generally be arranged in advance with safety. In less well-known regions, however, the possibility that the same formation may require treatment under different names in adjoining folios will have to be accepted as a necessary evil, largely outweighed by the positive advantages of adopting the lithologic unit as the basis for mapping.

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GLACIAL WORK IN THE WESTERN MOUNTAINS IN 1901.[1]

DURING the season of 1901 some time was given to the study of Pleistocene problems in the western mountains. Four small parties, beside the writer, were in the field. The work of three of the four parties was the somewhat detailed study of selected areas, and was intended to make known the general conditions of glaciation at several somewhat widely separated localities. When a sufficient number of selected areas have been studied similarly, the results will afford a basis for preliminary conclusions concerning the course of Pleistocene history in the western mountains, and will be helpful in guiding future work. The work of this summer was intended as the beginning of study looking to this end.

The writer spent about six weeks in the region, mostly in association with the parties referred to. One party was in northwestern Montana, east of the Rockies; one farther west, on the western side of the Rockies, in northwestern Montana, northern Idaho, and eastern Washington; one in the Wasatch Mountains; and one in the mountains of New Mexico, a few miles northeast of Santa Fé.

The following brief summary will give some idea of the work done:

NORTHWESTERN MONTANA, EAST OF THE ROCKIES.

Mr. Fred H. H. Calhoun, accompanied by Mr. Bruce McLeish, spent three months in the northwestern part of Montana. The area studied, some 8000 square miles in extent, lies just south of the 49th parallel, and just east of the Rocky Mountains. It is the area in the angle between the Continental ice sheet from the northeast, on the one hand, and the Cordilleran ice sheet from the northwest, and the mountain glaciers from the west, on the other.

[1] Published by permission of the Director of the U. S. Geological Survey.

The moraine formed by the northeastern ice sheet of the Wisconsin epoch was traced from Fort Benton, *via* Choteau, to the point where it crosses the 49th parallel, about longitude 112° 20′. From this point the moraine bends to the west and continues in this direction to the Watertown River, where it turns to the north, its course being nearly parallel to the mountains.

The moraines of fourteen glaciers from the Rocky Mountains were mapped. The recessional moraines of both the valley and continental ice masses were studied as far as time permitted. Study was also made of the extent of valley trains and outwash plains, and of the lakes which existed in front of the ice during the glacial period.

Among the results of the work, the following may be mentioned:

1. The westward and southwestward extension of the Wisconsin drift is greater than had been supposed.

2. The till of the northeastern ice sheet and that of the mountain glaciers overlap just south of the 49th parallel, between the meridians of 113° 10′ and 113° 15′. At no other point south of the boundary line did the ice from opposite directions occupy the same territory; but in Two Medicine Valley (latitude 48° 30′) the ice from the east advanced to within two miles of the position occupied at an earlier time by the ice from the mountains.

3. The ice sheet from the northeast reached its most advanced position after the valley glaciers from the west had retreated, for the drift of the former overlies the drift of the latter at various points, both north and south of the national boundary. In some cases the till from the northeast overlies the till from the west. This is true in the locality mentioned under 2, and farther north in the valleys of St. Mary's River, Belly River, and Lees Creek. In other places the till from the east overlies fluviatile deposits connected with the western drift, but extending down the valleys some miles beyond (east of) the ends of the mountain glaciers. In still other cases lacustrine

and berg deposits, having their source in the northeastern ice, overlie the till laid down at an earlier time by the mountain glaciers.

4. The valley glaciers belonged to a recent epoch. They were certainly not earlier than the Iowa epoch, and probably as recent as the Wisconsin.

5. The drift of the northeastern ice sheet is of Wisconsin, possibly late Wisconsin age.

6. So far as the evidence gathered shows, the length of time which elapsed after the deposition of the Rocky Mountain drift, and before the deposition of the drift of the ice sheet from the northeast, was not great.

7. The time since the last glacial epoch, as shown by several lines of evidence in the area studied, seems to have been geologically short.

8. The Sweet Grass Hills, situated just south of the 49th parallel and about thirty miles back from the edge of the ice sheet from the northeast, were not covered by the ice. The hills stood as three great nunataks, the highest reaching about 2000 feet above the surface of the ice.

9. The slope of the surface of the continental ice sheet between its edge and a point 25 miles back from its edge was estimated at about 50 feet per mile. This determination was made in the vicinity of the Sweet Grass Hills. The slope of the surface of the ice in various valleys was also determined.

10. The existence of a long narrow lake in front of the edge of the Continental ice sheet, and between it and the mountains, was proved, and its extent determined.

11. Considerable changes in drainage were effected by the ice. Some data were gathered which throw light on the former courses of the Missouri, the Teton, and the Two Medicine rivers, and of Buck, Muddy, and Cut Bank creeks.

Besides these conclusions touching glacial problems, some other observations were made:

12. The region studied shows at least three periods of erosion, when the land stood at different levels.

13. The high-level quartzite gravels on the plains east of the mountains are believed to be deposits made by streams at the close of the first epoch of base-leveling recorded in the present topography.

14. The strata at the mouth of Sun River and Muddy Creek canyons contain fossils of Carboniferous age. Rocks of the same age prevail in the whole of the eastern face of the mountains, where their thickness is several thousand feet.

Some other scattering data were collected touching the general geology of the region studied.

BETWEEN THE ROCKIES AND THE CASCADES IN NORTHWESTERN MONTANA, NORTHERN IDAHO, AND EASTERN WASHINGTON

Messrs. George H. Garrey and Eliot Blackwelder spent most of August and September in the study of glacial phenomena in northwestern Montana, northern Idaho, and northeastern Washington, most of the time being spent in the latter state, between Chelan Falls and Newport. The moraine of the ice lobe which came south through the Okanogan Valley, loops southeastward from Chelan Falls to a point about six miles west of Coulee City, where it bends northeastward to a point five miles north of the city, on the bluff of the Grand Coulee. Morainic material not aggregated into a marked terminal moraine, continues northward along the entire western rim of the Coulee. During glacial times the ice probably blocked the Columbia at its junction with the Grand Coulee, forcing the waters of the Columbia down the Coulee, as has been suggested by Russell and others. That glacial drainage followed the course indicated is suggested by the fact that the terraces of the Columbia above the Coulee are continuous with terraces in the Coulee.

Northeast of the junction of the Grand Coulee with the Columbia, the moraine of the Okanogan or Coulee City lobe takes the form of a well-developed ridge which, at a point about five miles north of the junction of the Columbia and the Grand Coulee, the most northerly point where it was seen, was trending

slightly to the west of north. After continuing northward for a distance, this moraine probably loops eastward around the mountains in the Colville Indian Reservation, connecting with the moraine of the ice lobe which occupied the Columbia valley, north of its junction with the Spokane. The Okanogan or Coulee City ice lobe was about thirty-five miles wide in the latitude of Chelan Falls, and nearly fifty miles wide at the upper end of the Grand Coulee.

The moraine of the ice lobe which came down the valley of the Columbia, just west of the meridian of 118°, was traced southward from a point in the Colville Indian Reservation about three miles west of Kettle Falls on the Columbia, to the point where it crosses the Columbia seven miles southwest of Fruitland. Between these points, the moraine lies three to six miles west of the Columbia. Just east of the Columbia the moraine is lost in the terraces at the junction of the Columbia and Spokane valleys. From this point the moraine was traced northeastward, passing about three miles east of Fruitland, and thence along the west face of the mountains, to the Huckleberry Mountain in the S. E. corner of Tp. 32, R. 38, E. (about latitude 48° 15′). At this point it loops around and over the northeastern end of this mountain, and then turns southward in the Colville River Valley. The glacier of the Columbia Valley had a width of about six and one-half miles in latitude 48°, and a width of about fifteen miles, fifteen miles farther north.

As already mentioned, the moraine of the Columbia glacier loops over and crosses Huckleberry Mountain and becomes continuous, in the Colville Valley, with a lobe of ice which descended that valley to Springdale. The moraine of the east side of this lobe was traced northward along the mountains east of the Colville Valley, to Old Dominion Mountain, seven miles east of Colville. This seems to be the latitude where the moraine swings across the mountains to the east, though the crossing was not demonstrated. The Colville glacier had a width of about thirteen miles at Valley, about eight miles north of the southern end of the lobe. The width of the combined Colville and

Columbia glaciers just north of their union (lat. 48° 15′ approximately), was about thirty-three miles.

In the Pend d'Oreille Valley there was another ice lobe, which extended down the valley to a point three miles southwest of Davis Lake. To the northwest this moraine is believed to connect with that of the Colville lobe, north of Old Dominion Mountain, though this connection was not established. The moraine of this lobe crosses the Pend d'Oreille River to the eastward at the great bend of the stream eight or ten miles above Newport. East of the Pend d'Oreille the moraine of the east side of this ice lobe was judged, on the basis of topography, to turn northward.

Another ice lobe came down the Kootenai Valley, but its southernmost limit was not determined. On the basis of data gathered at other times by Professor Chamberlin and the writer, the ice of the Kootenai Valley is believed to have extended to the southern boundary of Pend d'Oreille Lake. It is possible that the Kootenai lobe connected to the northwestward with the Pend d'Oreille lobe; but, if so, the connection is well to the north of Bonners Ferry, and probably north of the boundary line.

It remains to be determined whether the Okanogan, Columbia, Colville, Pend d'Oreille, and Kootenai glaciers were marginal lobes of a single continuous ice sheet, the body of which lay to the north, or whether some of them had separate sources in the mountains. The connection of the second and third of these lobes was established, and data at hand make the connection of the third and fourth seem probable. The connection of the first with second, and of the fifth with fourth, if such connection exists, is probably near the boundary if not beyond it. In any case, the glaciers partially traced out were large — quite beyond the Alpine class.

A few data concerning glaciation farther east were also gathered. General glaciation did not occur as far south as Newport at the east line of Washington. Above Libby (in the Kootenai Valley near the west line of Montana) there was gen-

eral glaciation from the north, though a few miles south of the river in this longitude drift from the north comes in contact with drift from the Cabinet Mountains. Whether the glaciation from opposite directions was contemporaneous, was not determined. Deposits of lacustrine clay some 300 feet thick in the valley near Libby, point to notable interruptions of drainage during glacial time, and probably to considerable changes since.

The Flathead valley contained a great glacier which advanced southward beyond the southern end of Flathead lake, though the southern limit of the ice was not traced out this season. In the latitude of Kalispell, the ice of this valley was about 3000 feet thick, as shown by the height to which the west face of the Kootenai Mountains east of the valley, was glaciated. The general direction of ice movement in this valley at Kalispell, and between this place and the lake, was south-southeast. The main body of the ice, therefore, came down the valley from the north northwest, and not from the mountains immediately east or northeast, though the main glacier was reënforced to some extent by ice from this direction. The source of ice which moved to the south-southeast was not determined. One lobe of the Flathead glacier moved southwest up the valley of Ashley Creek (the valley followed by the Great Northern Railway west of Kalispell), and another advanced westward a short distance beyond the end of the west arm of Flathead Lake.

The face of the Kootenai Mountains east of the Flathead Valley is abrupt, and not deeply indented. From the slight amount of study given to this face of the range, it would appear that local glaciation here was not of great extent or severity, for some of the considerable mountain ravines opening out to the west afford little evidence of glaciation. On the other hand, glaciation was severe in some of the valleys, as in that followed by the Great Northern Railway east of the Flathead Valley.

THE WASATCH MOUNTAINS.

Mr. Wallace W. Atwood spent about two months in the study of the glacial phenomena of the Wasatch Mountains. He was

accompanied and assisted by William Peterson, M. J. Averett, H. B. Atwood, and Arthur Church.

The portion of the Wasatch Mountains studied lies between the parallels of 40° 15′ and 41°. The maximum width of the range in this latitude is about twenty miles. The total area examined for glacial phenomena was about 1000 square miles.

Within this area, the positions of fifty Pleistocene glaciers exceeding a mile in length were determined. Traces of several smaller glaciers and of more than a dozen névé fields were also found and mapped. Of the fifty larger glaciers, seven reached the shore line of Lake Bonneville, and the moraines of at least three of them are clearly seen to be partially buried by the fluviatile deposits near the shore, or possibly by the shore deposits of the lake itself.

The elevation of a catchment basin necessary to give rise to a glacier in this region, was between 8000 and 9000 feet, and, except where the basins were very favorably situated, the latter figure is more nearly correct.

The crest line of the Wasatch Mountains is near the eastern border of the range. The valleys of the west slope are therefore much longer than those of the east, and the glaciers of the two slopes were, in a general way, of corresponding lengths. The number of ice tongues on the west was also much greater than on the east. Of the fifty glaciers over one mile in length, forty-six were west of the crest, and but four east of it. Of the ten glaciers which reach or exceeded five miles in length, nine moved westward and but one eastward. The Little Cottonwood glacier on the west slope was twelve miles long, while the greatest length reached by any glacier on the east slope was five miles. East of the crest, one glacier descended to an altitude as low as 6000 feet, and two others descended to 7000 feet. On the west slope fourteen glaciers descended to an altitude of less than 6000 feet, and seven to 5000 feet.

The greater number and size of glaciers on the west side of the range as compared with the east side, were determined by (1) the larger catchment basins, and (2) the heavier snowfall. A

third factor, of local importance, was the accumulation of snow in catchment basins among the lofty peaks of two east-west divides, lying west of the main crest. These basins, in many instances, furnished tributary glaciers to the main canyons, and thus greatly increased the amount and strength of the work done by the ice on the west side of the range.

Glaciation was not only more extensive, but also more vigorous on the west side of the range than on the east. This is shown by a more complete cleaning out of loose material from the glaciated valleys of the west slope, by the more complete reduction of their asperities of surface, by the greater deepening of the main canyons on this side, leaving their tributary valleys "hanging" 200 to 300 feet above, and by the development of more massive moraines. The moraines of the east-slope glaciers are insignificant in comparison with those of the west slope glaciers.

The work of the season removes all doubt as to the duality of the ice age in the Wasatch Mountains. There were at least two ice epochs separated by a long interglacial interval. Evidence of more than two epochs was not found. The basis for the above conclusion is as follows:

1. In several valleys there are outer moraines, much older than the inner moraines of the same valleys. A considerable tunnel exposure in one of these outer moraines showed essentially all of the abundant granite bowlders, up to four feet in diameter, so thoroughly disintegrated that they had been cut through with picks and shovels in the excavation of the tunnel. Most of them could be crumbled by the hand. This condition of things was not superficial, but held to the depth of twenty feet, the deepest point of exposure.

2. In certain glaciated canyons there are such variations in the amounts of postglacial change (weathering, erosion, etc.) which different portions of the drift and valley walls have suffered, that it seemed necessary to postulate much longer exposure for certain parts than for others. In all such cases, the drift which appears to be older, extends beyond that which

appears to be younger. The ice of the earlier epoch, therefore, seems to have been more extensive.

3. Two distinct sheets of drift were found at several points in the valleys of both the North and South Forks of the American Fork. These sheets of drift are separated by a soil twelve to eighteen inches thick. In the same localities, the soil on the surface of the upper drift sheet, formed since the last retreat of the ice, is from four to six inches thick. So far as the thickness of soil is a basis for estimating time, it would indicate that the interval between the ice epochs was longer than the time since the last.

The topography of the region examined was somewhat modified by glaciation. The valleys which were occupied by ice are usually U-shaped, and their slopes are commonly smoothed off as far up the sides as the ice reached. Such forms are in sharp contrast with the V-shaped canyons and rugged slopes of the valleys not occupied by ice. In some of the glaciated valleys massive moraines were built up. These are sometimes in the canyons, and sometimes at their débouchures, according to the position which the ends of the glaciers reached at the time of their maximum extension. When tributary glaciers joined the main, medial moraines were formed, and as the ice melted, these moraines were left as ridges, parallel with the course of the valley. Recessional moraines are frequently found crossing the valleys as crescentic ridges, convex down stream. These ridges often served as dams, above which lakes accumulated, rose, and overflowed. The outlet streams of such lakes cut gorges in the moraines. Near the heads of many valleys the ice gouged out rock basins, 50 to 200 feet in diameter and from 5 to 20 feet in depth. At least thirteen of the thirty-six glacial lakes mapped, are in rock basins apparently made by the ice.

The relation of the moraines at the west base of the Wasatch, to the fluviatile (or shore) deposits in the Bonneville basin, is such as to indicate, as Gilbert has pointed out, that the last advance of the ice from the mountains occurred during a late period in the history of Lake Bonneville. The close correlation

of the earlier ice epoch with the earlier wide extension of the Bonneville waters cannot as yet be asserted, although the data at hand strongly suggest the contemporaneity of the early expanded stage of Lake Bonneville and the early glaciation.

THE MOUNTAINS NEAR SANTA FÉ

Messrs. John E. Webb and William A. Averill spent about one month in the mountains of New Mexico, a few miles northeast of Santa Fé. The area studied was the Santa Fé range of the Rockies, which traverses the northeastern portion of New Mexico, running in a general north-northeast, south-southwest direction through the adjacent parts of Santa Fé, Rio Arraba, Mora, and San Miguel counties, between the parallels of 35° 45′ and 36°, and the meridians of 105° 35′ and 105° 50′. The aggregate area comprises about 250 square miles.

The height of the range in the area studied varies from 7000 feet to 13,306, feet, the latter being the altitude of the highest of the Truchas peaks. The altitude which seems to have been necessary for the generation of glaciers was 11,700 to 12,000 feet. The following peaks attained the requisite height: Lake peak, 12,380 feet; Baldy peak, 12,623 feet; Pecos Baldy (Cone peak?), 12,550 feet; Jicarilla peak, 12,944 feet; and the Truchas group, the highest peak of which is 13,306 feet. Clear evidence of glaciation was not seen on lower peaks, though it cannot be said that many of the lower peaks were studied in the detail necessary to demonstrate the complete absence of glaciation.

Heading against these peaks and their connecting ridges, fifty cirques bearing evidences of glaciation were observed. Névé fields, with incipient motion, existed at some points where well-formed glaciers did not develop. Sixteen of the cirques are in the group of mountains (Lake, Baldy, and associated ridges) at the head of Santa Fé Creek; seven in the Pecos Baldy group; twelve among the Truchas peaks; and fifteen about Jicarilla peak, and the ridge between it and the Truchas peaks. Of these cirques, twenty-five open toward the east, thirteen

toward the north, seven toward the south, and five toward the west. The cirques range from one-fourth of a mile to two miles in width, and from one-eighth of a mile to two and one-half miles in length, and from 150 to 1000 feet in depth. Most of them contain lakes or ponds, some of them as many as six, and almost all contain flats or bogs, indicating the former existence of standing water, where there is none now. The total number of ponds and lakelets seen was about eighty. Since they were seen in the rainy season, the number of permanent bodies of standing water may be less.

The longest glacier track studied is in the valley of the Santa Fé Creek. The ice emanating from three cirques united to form a single glacier which Messrs. Webb and Averill think extended some seven miles down the valley, its lower end reaching down to an altitude of about 9200 feet, the lowest altitude, so far as seen, to which the ice descended. The largest area of glaciation from a single source is that on the east side of the Pecos Baldy group, in the valley of Jack's Creek, while the largest continuous area of glaciation (to which the ice from several sources contributed) is that along the group of mountains at the head of Santa Fé Creek.

The moraine matter left in the cirques, and in the valleys below them, often has a pronounced hummock-and-hollow topography. Its composition varies from point to point. The chief accumulations are in the bottoms of the valleys. The morainic matter is often disposed in ridges most commonly roughly parallel to the axes of the valleys and to the direction of ice movement, but often oblique or even at right angles to this direction.

Striæ were found on *roches moutonnées* in several places, while smoothed and polished rock surfaces are of frequent occurrence.

The higher ridges and peaks of the glaciated regions are serrate, but serrate crests are confined strictly to the higher parts of the range. Serration often characterizes the tops of the mountains, on the sides of which the glaciated cirques lie.

OTHER OBSERVATIONS

In addition to the foregoing work, some further data were gathered at several points, touching Pleistocene geology in the West. It was found that loess has somewhat extensive development in eastern Washington and northeastern Oregon, though its limits were not determined. It is widespread in Douglas, Lincoln, Whitman, Columbia, Walla Walla and probably Spokane counties, Washington. It is very generally distributed over the northern part of Umatilla county, Oregon. In geographic distribution it seems to correspond, in a general way, with the great wheat belt of the states mentioned. In topographic distribution, it has the general habit of the corresponding formation in the Mississippi basin; that is, it has a preference for considerable elevations. So far as seen, however, its disposition to follow streams is less pronounced than in the Mississippi basin east of the Missouri. Its variations in composition and structure, too, are similar to those of the loess of the interior. Its thickness is very variable, and for the most part undetermined, but locally it is at least twenty-five to thirty feet thick, and its maximum is probably considerably more. In many places, as at Bolles Junction (Walla Walla county), it abounds in calcareous concretions of the usual loess type. In other places, as at Alto (Columbia county), it assumes the columnar structure, so characteristic of the loess of some other localities where the formation is well known. In many places, it constitutes the entire mantle rock. In some places it is associated with sand, which may be either beneath it or interbedded with it; and in other localities it contains considerable beds of volcanic ash. The sand and volcanic ash associated with it are sometimes distinctly stratified. In some cases, the stratification is clearly the work of wind, but in others this was not evident. The impression gained was that much of the loess seen is of eolian origin.

Observations on glaciation were made at several points, aside from those enumerated in the preceding pages. Data sufficient for the intelligent direction of future Pleistocene work were

gathered for a number of localities where detailed work in the near future seems desirable. In addition to preliminary studies of this sort, glaciation was found to have occurred in some localities from which it has not heretofore been reported. For example, it was found that glaciers affected the north slope of both the Spanish Peaks of Colorado. These mountains, 12,708 and 13,623 feet high respectively, appear to have represented about the limiting conditions for glaciation, for the glaciers of both mountains were small, and confined to their northern slopes. One of the limiting conditions here was doubtless the small area which could serve as a catchment basin on either peak. Had the areas of these mountains been larger, more considerable glaciation would doubtless have been developed at this altitude.

It was found, among other things, that the detailed study of glacial problems will locally have an important economic bearing. An extensive placer mining plant is being established at Breckenridge, Col., to wash the glacial moraine matter of the Blue River valley, and the gravels of the valley train below.

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Reviews

Preliminary Description of the Geology and Water Resources of the Southern half of the Black Hills and Adjoining Regions in South Dakota and Wyoming. By N. H. Darton. [Extract from the Twenty-first Annual Report of the U. S. Geol. Surv., 1899–1900, Pt. IV, Hydrography; pp. 489–599; Plates LVIII–CXII; Washington, 1901.]

The topics discussed in this paper are topography, stratigraphic-geology, geologic structure, geologic history, water resources, minerals, soils, climate and timber. The Black Hills rise out of the Great Plains as a small group of forest covered mountains several thousand feet high. Their central area, composed of mountains and parks, is of crystalline schists and granites. Bordering the old rocks is a belt of limestone plateaus surrounded in turn by the Red Valley, a depression resulting from the etching out of a layer of softer rock — the Spearfish formation of Triassic age. Beyond the valley and concentric with it is the hogback range, due to a hard sandstone not weathered down. Still farther outward are the Plains. Careful descriptions of the lithologic characters and the distribution of each formation follow; in fact the paper is descriptive rather than theoretic, but does not fail to call attention to broad features and to make generalized statements.

The oldest sediments are Cambrian. They are probably of later Cambrian time and give one more item of evidence leading to the conclusion that Cambrian time was one of extensive submergence. Here Cambrian sands were deposited along seashores and in estuaries with gradual submergence and probable ultimate covering of the crystallines with sediments of this age. The chief evidence is the presence of fine grained deposits in the Upper Cambrian such as are not formed near land. At present no Silurian or Devonian strata occur. The reason is problematic. Either there was no deposition or else little deposition and subsequent removal. Carboniferous time began with deep water and marine conditions, and was consummated after the laying down of 800–1000 feet of rock. Triassic and Jurassic are both present and

distinguishable because an abrupt change in the character of the sediments and some erosion occur at the top of the former. Cretaceous sediments have accumulated to the thickness of about 6000 feet and consist largely of shales with some sandstone and a little limestone. Tertiary rocks represented by the White River formation are mostly of clay; fuller's earth, sand, limestone, and grits occur. Still later deposits are classed under earlier and later Pleistocene beds.

The structure of the region is that of an elongated low dome with anticlinal wrinkles or spurs running off from the central area. The maximum uplift was north of Harney's Peak and amounted to 9000 feet.

One of the most admirable features of this paper is the abundance of real geographic material embodied in it. The region described is one of submaturely dissected, domed mountains in which all the sediments have been removed from the central portion leaving subdued hills and broad parks of crystalline rocks. The concentric arrangement of the different formations is due to the uplift and to the processes of erosion which though similar for all strata, have been much more effective in reducing some than others. Soft layers are found etched out, hard layers standing up, but each and every one has its peculiar forms. Thus geography follows stratigraphy.

Attempts by the author, more or less successful, to reconstruct the geography of the locality at different periods and to follow it through its phases, are persistently made, and they yield an interesting element in the work. In this connection there is a contour map showing the present relief of the upper surface of the Dakota sandstone over a part of the area. This kind of work forms a very desirable feature.

The considerable eastward dip away from the Black Hills, where most of the formations outcrop, together with other necessary features, gives good artesian conditions to this region. Many wells reaching the Dakota and Lakota sandstones flow with good water. The scanty rainfall on the plains eastward renders these wells very useful. Many streams diminish or cease by sinkage when they cross the sands. Along Cheyenne and Fall rivers there is some opportunity for irrigation — good bottom lands and reservoir space, with fair water supply.

Soils are mostly residuary from underlying rocks. Overplaced soils and sand dunes are found in places. "Sedentary soils" may be criticised. No soil is sedentary in the sense that it does not move. "Soil in place" or preferably "residual soil" more adequately carries the

meaning. The relation of soils to underlying rocks, and of crops to soils make very instructive points. Considerable mineral wealth is found in coal, gypsum, and lithographic limestone in large slabs. These of sufficient size to be valuable are not obtainable elsewhere in the United States.

The notes and diagrams on climate are good but disappointing because they do not indicate the significance of the condition of the meteorologic elements from a geologic point of view. There is little utility in giving space in a geologic report to climatic notes unless some use is made of them. The climate must have characteristic influence on erosion, soil formation, soil transportation, etc. The position of volcanic ash to the eastward of the volcanoes, now extinct, just west of the Black Hills shows similarity of winds in the White River time to those of the present time.

Why cannot the U. S. G. S. reports, in discussing such a region as this, have a section on geography? It should embrace most if not all of the section here devoted to topography, but should go farther with the question, incorporating some that is said under soils, climate, water resources, etc., and then discuss the influenee of relief, soil and water on products, transportation, distribution of plants and animals, man, and his various occupations.

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The High Plains and Their Utilization. By WILLARD D. JOHNSON. [Extract from the Twenty-first Annual Report of the U. S. Geol. Surv., 1899–1900, Pt. IV, Hydrography; pp. 601–768; Plates CXIII–CLVI.]

THE High Plains, as defined in the first chapter, correspond approximately to the Central Plains. They form a belt extending from central Texas northward across Oklahoma and western Kansas into Nebraska, but are more characteristic in Texas because less eroded. By topographic difference they constitute a topographic unit of the great geographic unit—the Great Plains. The High Plains practically have no drainage, hence their surface is in general a dead level known locally as the "Flats."

Chapter II discusses the origin of these plains. They are the

remnants of an old débris apron built in the latter half of Tertiary time, and preserved because of lack of sufficient precipitation to produce run-off. The author takes the ground that this apron of waste was deposited and arranged by streams, but shows that the streams were not of the ordinary type. A careful analysis of arid region stream work leads to the conclusion that "there is no such thing as sheet flow" in the sense of a uniform flood of water and waste, but that the more or less perfect sheet is "one of intimately lacing threads of current."

The deposits of which the plains are composed are the result of this stream work and not of still water work. As proof of the proposition, the author finds the following facts:

(1) Wide distribution, at all depths of gravels, which decrease in size from the mountains. (2) The size of these coarse materials is often that of cobbles. (3) Gravel courses run east and west and are cross-bedded—marking the channel courses of eastward flowing streams. (4) Sand bed salso occur in courses elongated east and west in the "clays." (5) Interlaced stream beds occur as shown where erosion has disclosed them. (6) Even most clay beds are thin and elongated east and west.

Mr. Johnson finds the "mortar-beds" cutting across the local bedding of sands and gravels, and he considers the beds to have been formed by the cementation of the coarse materials at the level of the ground water by salts carried down in the sinking surface water. It appears that his explanation of the distribution of water in these gravels is similar to that of water distribution in the morainic materials of Illinois and Indiana, as worked out by Leverett and others, and stated by Leverett in the Eighteenth Annual Report of the U. S. Geol. Surv. Pt. IV.

Chapter III is a discussion of the "deficiencies of climate." The climate of the High Plains is described as subhumid. It varies from humid to arid through a period of years. The author very properly states that the amount of precipitation is not the only factor in determining the climate, or even the arability of a region. The Dakota wheat fields actually have less rainfall than the Staked Plains of Texas, but the rainfall is more effective in Dakota. In Texas (1) rainfall is more spasmodic; (2) temperature is higher, increasing evaporation and decreasing relative humidity; (3) there are more hours of sunshine, and (4) greater wind movement. In the summary he reaches

two conclusions which are thoroughly borne out by the facts and discussion. (*a*) A truer index of climate than rainfall is relative humidity. (*b*) Observations covering a quarter of a century indicate that no change in climate, save that of short-period oscillations, takes place. While the High Plains area is a climatic unit, it shows evidence of agreement in the series of climatic changes through Pleistocene, with the Great Basin lake fluctuations, and with the advance and retreat of the Rocky Mountain glaciers.

The fourth chapter gives a graphic picture of the boom of 1888–1893, with the subsequent disasters, and some suggestions as to what may be grown on the High Plains.

Chapter V proves the impossibility of general irrigation within the High Plains. The facts are as follows: (1) The rainfall and streams are wholly inadequate; (2) the mountain streams from the west are so loaded with waste that ponds to retain their waters would be exceedingly short-lived; (3) all mountain streams must pass through a broad, arid, fertile strip amply sufficient to utilize all their waters; (4) artesian water in very small quantity is found in the valleys, but the entire supply is altogether too small for general irrigation. This source, however, is sufficient to furnish water for a garden and ranch headquarters at occasional intervals.

In the closing pages there is a discussion of the origin of peculiar sink holes, and a theoretic explanation of the movements of underground waters. This last brings together considerable valuable material which formerly has been scattered and little known, but it presents scarcely anything new.

The author thus states his purpose at the outset, and he accomplishes his object: "To show that the High Plains, except in insignificant degree, are non-irrigable, either from streams, flowing or stored, or from underground sources, and that, therefore, for general agriculture, they are irreclaimable; but that, on the other hand, water from underground is obtainable in sufficient amount for reclamation of the entire area to other uses; that such reclamation has in fact already begun, and is in progress of gradual, but sure development; and that it will be universally profitable."

This paper will be of great service to those in the arid and subarid regions, and to those who may contemplate immigration thither, because it gives authentic information concerning fertility and water-supply there. But the value of the paper is not alone in its descriptive

work. To science the able discussions of causes and effects, of climatic relations to geology, geography, and agriculture, of water-supply, etc., are the most attractive features. The pages devoted to underground water resources are specially strong. The only regret is that the paper is not finished.

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The Bauxite Deposits of Arkansas. By CHARLES WILLARD HAYES, U. S. Geological Survey, Twenty-first Annual Report, Part III, pp. 435–472. Maps and plates.

COMMERCIAL deposits of bauxite have been known in Arkansas since 1890, when they were first discovered by the State Geological Survey. The present report by Dr. Hayes represents, however, the first detailed systematic study of these deposits, and its appearance when developments are just beginning in the area, makes it a very timely one.

Preliminary to the description of the Arkansas deposits proper, the report opens with a brief summary of the "distribution of bauxite deposits in the United States." The Arkansas deposits are limited to a small area twenty miles long and five or six miles wide, lying south and southwest of Little Rock, in the adjacent parts of Pulaski and Saline counties. The most important deposits of the state are grouped into two districts, with less important isolated ones between. The general geologic and physiographic relations of the region are recounted in some detail, derived largely, as the author says, from the state survey reports. Three distinct groups of rocks are made out, namely, the Paleozoic sediments in the northwest, the Tertiary and recent sediments on the southeast, and areas of intrusive igneous rocks in the two bauxite districts. The Paleozoic rocks are similarly folded and closely resemble those of the Alabama-Georgia-Tennessee area of the southern Appalachians. The region was probably several times reduced to a nearly featureless plain, and sometime after the folding, probably, during Cretaceous, the igneous rocks were, according to Williams, intruded. Beginning with the Cretaceous, the region was several times invaded by the sea and Tertiary sediments still form a considerable part of the area.

In the detailed description of the deposits, the two districts are

separately described in some detail, and certain peculiarities possessed by each are pointed out. The few scattered isolated deposits are likewise described.

In the Bryant district, which is the most southwesterly one, the bauxite occurs in two distinct forms: (*a*) granitic bauxite, and (*b*) pisolitic bauxite. The granitic bauxite forms the basal portions of the beds, and in most cases rests immediately on a layer of kaolin, derived by the ordinary processes of decay from the syenite. The bauxite is spongy in texture with no trace of the pisolitic structure, but showing partial traces of the granitic structure in which the individual feldspars are replaced by a porus skeleton of alumina. It is probable, says Hayes, that this type of bauxite is in every case derived directly from the syenite by the decomposition of the feldspar and the eleolite, and the removal in solution of silica, lime and alkalis, the alumina alone remaining of the original constituents. The pisolitic type is more uniform than that of the Georgia-Alabama region and forms the upper parts of the beds. The two forms of ore are not separated, as a rule, in the same section, by any sharp and definite line.

In the Fourche Mountain district only the pisolitic type of the ore has been found, which, when nearest the syenite margin, rests on a layer of kaolin as in the Bryant district. Those deposits more distant from the syenite margin are probably interstratified with sedimentary beds of Tertiary age.

The scattered isolated deposits found between the two districts resemble in their mode of occurrence the Georgia-Alabama deposits.

The deposits are in beds or layers, which range in thickness from zero to forty feet, and have a probable average thickness of ten to fifteen feet for the two districts, and two to five feet and more in case of the isolated bodies of ore.

In chemical composition the Arkansas bauxite varies within wide limits. The granitic type is the purest, and in selected samples contains less than 3 per cent. of silica and 1 per cent. of iron oxide, and corresponds in composition to the formula $Al_2O_3 3H_2O$ — the trihydrate of alumina. In the white bauxitic kaolins the silica ranges as high as 20 to 30 per cent., and in extreme cases the iron oxide reaches 50 per cent. in some of the highly ferruginous types of the ore.

Concerning the origin of the Arkansas bauxite deposits Dr. Hayes says that they are so intimately associated with the igneous rocks of the region that genetic relationship between the two is at once sug-

gested. The characteristic pisolitic structure of the upper portion of the deposits indicates chemical precipitation. The granitic bauxite forming the lower or basal portions of the beds, and the bowlders, are evidently of a different origin. The bauxite was probably laid down on the syenite rather than on the kaolin, as there is no indication that the kaolin is an intermediate product between the fresh syenite and the bauxite.

In his report on the igneous rocks of Arkansas Dr. J. Francis Williams suggests two theories for the accumulation of the bauxite. First, that the bauxite was formed by the decomposition of a bed of clastic material, derived principally from the syenite. The second, which he regarded as the most probable one, involved the action of the waters of the Tertiary sea on the still highly heated igneous rocks, in which, under high temperature and pressure, the constituents of the syenite were dissolved and brought to the surface in solution, the water emerging as hot springs. In the discussion of these theories Dr. Hayes points out serious difficulties to both.

In the last part of the report Dr. Hayes treats of the "Economic Relations" under "Development;" "Amount of Ore," which includes a tabular statement of the estimate of the amount of ore in the Arkansas bauxite region, and, according to the author's calculations, shows the total amount estimated in outcrops to be 6,608,500 long tons, and the total amount under cover 43,711,200 long tons; "Quality of the Ores;" and "Mining and Preparation of the Ore for Market."

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Recent Publications

—Adams, Charles C. Baseleveling and its Faunal Significance, with Illustrations from Southeastern United States. [Reprint from The American Naturalist, Vol. XXXV, No. 418, October, 1901.] Ginn & Company, Boston, 1901.

—Baker, Frank Collins. Some Interesting Molluscan Monstrosities. Transactions of the Academy of Science of St. Louis, Vol. XI, No. 8. Issued November 26, 1901.

—Blasdale, Walter C. Contributions to the Mineralogy of California. [Bulletin of the Department of Geology, University of California, Vol. II, No. 11, pp. 327–348.] Berkeley, November, 1901.

—Coleman, A. P. Glacial and Interglacial Beds Near Toronto. [Reprinted from the Journal of Geology, Vol. IX, No. 4, May–June, 1901.] The University of Chicago Press.

Marine and Freshwater Beaches of Ontario. [Bulletin of the Geological Society of America, Vol. XII, pp 129–146.] Rochester, March, 1901.

—Collie, George L. Physiography of Wisconsin. [Reprinted from the Bulletin of the American Bureau of Geography, Vol. II, No. 3, September, 1901.] Winona, Minn., 1901.

—Congrès Geologique International. Comptes Rendus de la VIII^e^ Session, en France. Imprimerie Le Bigot Frères, Lille. Paris, 1901.

—Darton, Nelson Horatio. Preliminary Description of the Geology and Water Resources of the Southern Half of the Black Hills and Adjoining Regions in South Dakota and Wyoming. [Extract from the Twenty-first Annual Report, United States Geological Survey, 1899–1900. Part IV—Hydrography.] Washington, 1901.

—Dinges, J. Textbuch zum Relief der Nördlichen Kalkalpen. 1:50000. A. Fackler, Mindelheim (Südbayern), 1901.

—Dubois, Eugene. Paradoxe klimatische toestanden in het Palæozische tijdvak, beschouwd in verband met den vroegeren aard der zonnestraling. [Overgedrukt uit de Handelingen van het Achtste Nederlandsch Natuur- en Geneeskundig Congress.]

—Eckel, Edwin C. The Portland Cement Industry in New York. [Published, by permission of the State Geologist of New York, in Engineering News, May 16, 1901.]

The Snakes of New York State: An Annotated Check List. [Reprint from the American Naturalist, Vol. XXXV, No. 410, February, 1901.] Ginn & Company, Boston, 1901.

—FINSTERWALDER, S., ET E. MURET. Les Variations Périodiques des Glaciers. Sixième Rapport, 1900. [Extrait des Archives des Sciences physiques et naturelles, T. XII, 1901.] Librairie Georg & C^ie., Genève. 1901.

—GOULD, CHARLES NEWTON. The Dakota Cretaceous of Kansas and Nebraska, and other papers. [From Vol. XVII, Transactions Kansas Academy of Science.] Topeka, 1901.

—HARKER, ALFRED. Ice-Erosion in the Cuillin Hills, Skye. [Transactions of the Royal Society of Edinburgh, Vol. XL, Part II (No. 12).] (With a map.) Robert Grant & Son, 107 Princes Street, Edinburgh; and Williams & Norgate, 14 Henrietta Street, Covent Garden, London, 1901.

—HOBBS, WILLIAM HERBERT. The Newark System of Pomperaug Valley, Connecticut. With a Report on Fossil Wood by F. H. Knowlton. [Extract from the Twenty-first Annual Report U. S. Geological Survey, 1899–1900, Part III—General Geology, Ore and Phosphate Deposits, Philippines.] Washington, 1901.

The River System of Connecticut. [Reprinted from the JOURNAL OF GEOLOGY, Vol. IX, No. 6, September–October, 1901.] The University of Chicago Press.

—KEILHACK, CONRAD. Geologisch-morphologische Übersichtskarte der Provinz Pommern. Mit Benutzung der Aufnamen der Geologischen Landesanstalt entworfen. In Vertrieb bei der Königlich Preussischen Geologischen Landesanstalt u. Bergakademie, Berlin, N. 4, Invalidenstrasse 44.

—KUNZ, GEORGE F. The Production of Precious Stones in 1900. [Extract from Mineral Resources of the United States, Calendar Year 1900: David T. Day, Chief of Division of Mining and Mineral Resources, U. S. Geological Survey.] Washington, 1901.

—LANE, A. C. The Economic Geology of Michigan in its Relation to the Business World. [Lecture delivered at the Field Columbian Museum, Chicago, November 2, 1901.] The Michigan Miner, Saginaw, Mich., December 1, 1901.

—MERRILL, GEORGE P. On a Stony Meteorite, which fell near Felix, Perry County, Alabama, May 15, 1900. [From the Proceedings of the United States National Museum, Vol. XXIV, pp. 193–198 (with Plates XIII, XIV).] Washington, 1901.

—MOLENGRAAFF, G. A. F. Géologie de la République Sud-Africaine du Transvaal. [Extrait du Bulletin de la Société Géologique de France.] 28, Rue Serpente, VI, Paris, 1901.

—United States Department of Agriculture. Report No. 70. Exhaustion and Abandonment of Soils. Testimony of Milton Whitney, Chief of Division of Soils, before the Industrial Commission. Washington, 1901.

—United States Geological Survey. Twenty-first Annual Report, 1899–1900. Part I, Director's Report, including Triangulation, Primary Traverse, and Spirit Leveling. Part VI, Mineral Resources of the United States, 1899; Metallic Products, Coal, and Coke. Part VI (continued), Mineral Resources of the United States, 1899; Non-metallic Products, except Coal and Coke.

—WARD, LESTER F. Geology of the Little Colorado Valley. [From the American Journal of Science, Vol. XII, December, 1901.]

—WARMAN, PHILIP CREVELING. Catalogue and Index of the Publications of the United States Geological Survey, 1880 to 1901. [Bulletin No. 177, U. S. Geological Survey.] Washington, 1901.

—Washington Academy of Sciences, Proceedings of the.

Papers from the Harriman Alaska Expedition, XXV. The Algae. [Plates XLIII–LXII.] By De Alton Saunders. Vol. III, pp. 391–486, November 15, 1901.

Papers from the Harriman Alaska Expedition, XXVI. Harrimanella, a New Genus of Heathers. [Text Figures 62–66.] By Frederick V. Coville. Vol. III, pp. 569–576, December 6, 1901.

Papers from the Hopkins-Stanford Galapagos Expedition, 1898–9. V. Entmological Results (5): Thysanura and Termitidæ. [Text Figures 47–57.] By Nathan Banks, U. S. National Museum. Vol. III, pp. 541–546, November 29, 1901.

Papers from the Hopkins-Stanford Galapagos Expedition, 1898–9, VI. The Isopods. By Harriet Richardson, Collaborator, Smithsonian Institution. Vol. III, pp. 565–568, November 29, 1901.

Descriptions of 23 New Harvest Mice (Genus Reithrodontomys). By G. Hart Merriam. Vol. III, pp. 547–558, November 29, 1901.

Seven New Mammals from Mexico, Including a New Genus of Rodents. By G. Hart Merriam. Vol. III, pp. 559–563, November 29, 1901.

Preliminary Revision of the Pumas (Felis Concolor Group). By C. Hart Merriam. Vol. III, pp. 577–600, December 11, 1901.

—WOODWORTH, J. B. The History and Conditions of Mining in the Richmond Coal-Basin, Virginia. [Transactions of the American Institute of Mining Engineers (Richmond Meeting, February 1901).]

—WRIGHT, FRED. EUGENE. Die Foyaitisch-Theralthischen Eruptivegesteine der Insel Cabo Frio, Rio de Janeiro, Brasilien. [Tschermak's Mineralog. und petrographische Mittheilungen, Bd. XX, Heft 3.] Alfred Hölder, Rothenthurmstrasse 15, Wien.

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